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Report of the State Geologist 1953-1954

Maine Geological Survey

Report

of the

STATE GEOLOGIST

1953-1954

Maine Development Commission

Augusta, Maine, July, 1955

MAINE GEOLOGICAL SURVEY

DEPARTMENT OF DEVELOPMENT OF INDUSTRY AND COMMERCE

PERSONNEL

1953

JOSEPH M. TREFETHEN, Ph. D.

State Geologist

Henry Allen	Geologist
William Forsyth	Geologist
Lawrence Wing	Assistant Geologist
Sewell Millett	Field Assistant
Francis Groselle	Field Assistant
Harold Kyte	Field Assistant

1954

JOSEPH M. TREFETHEN, Ph. D.

State Geologist

Henry Allen	Geologist
William Forsyth	Geologist
Harold Kyte	Field Assistant
John A. DeWilde	Geologist Aide
Winslow Krueger, Jr.	Geologist Aide

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REVIEW OF MAINE'S MINERAL OUTLOOK

JOSEPH M. TREFETHEN

In modern mineral industry three points stand out; and these, I think, have direct bearing on the mineral position of this state, and on the direction of our efforts to enhance that position. These points are:

1. Where the geologic nature of occurrence renders it possible, demand centers on those large deposits of great tonnage, rather than on small scattered deposits even though the latter may be of higher grade ores.
2. Technology is rendering economic deposits of grades that formerly were not commercial.
3. That some minerals, always in domestic demand, and in war-time critically short, are of highest strategic import.

With these ideas in mind, we turn now to a consideration of Maine's mineral resources.

Three questions come to mind:

1. What are we producing?
2. What is the outlook for new production?
3. What program will best advance our mineral position?

I shall attempt answers to these questions in order, avoiding technicalities and detail in the interest of brevity.

PRESENT PRODUCTION

Our mineral production at present is almost entirely of non-metallics. Structural materials, and gravel, crushed stone, dimension stone, cement rock, and structural clay products lead. These are basic for highways, airports, bridges, dams, and industrial construction of all types. Although supplies are large, and output expands with demand, this does not imply that we can assume that either private or public construction is taking full economic advantage of this type of resource.

Other non-metallics produced are slate, peat, feldspar, mica, beryl, and agstone.

Changes in styles of roofing and introduction of "white" kitchens have shifted the demands from slate shingles and sinks to electrical goods; and plastics are making inroads in that direction, also. New uses for slate waste are under study, as discussed in the paper on lightweight aggregates.

Agricultural peat has a steady production, principally from bogs in the eastern half of the state. Peat as a fuel has not been successfully produced here, although during war-time fuel shortage development was under consideration.

During war-time shortages, strategic mica was produced from quarries in western and southern Maine. The production in pounds of sheet mica was not large, but it came at a time of severe shortage and every pound counted. Little mica is currently produced at the low post-war prices which prevail.

Feldspar is steadily produced from western and southern Maine. The raw product is exported out of New England for manufacture chiefly of ceramics and porcelains.

Beryl, along with feldspar is produced at some mines in sparing quantity. This mineral and a few associates, under conditions of occurrence and existing price structure, are byproducts of feldspar mining.

Agricultural lime is ground raw limestone of high purity. The principal production is in the Rockland Area.

So much for the answer to the question, what are we producing. The mentioned products total some nine million dollars a year.

The second question raised is, What is the outlook for new production? There is a variety of ways to answer this. I shall attempt to do so by commodities.

For those commodities mentioned as currently produced, the outlook is good. In Maine as elsewhere, we experienced a post-war construction boom. However, we confidently anticipate increasing industrialization with attendant requirements for new construction, both public and private. This trend insures continuing rise in demand for structural materials. In particular, may be indicated increase in cement and brick manufacture. So far as I am aware, there is no brick plant in the state north of Bangor. Although brick clay is abundant, our rich northern county must import brick.

It appears certain, also, that requirements for highway and airport construction will far exceed those of the past. I would point out, too, that although it is almost certain that we have the raw ingredients for insulating materials, no manufacture of these exists in the state. With development of abundant and cheap power, this industry might well thrive in Maine.

Turning from the field of construction material, prospects for other types of production are far from discouraging. The vast deposits of low grade manganese bearing rock in Aroostook County are widely known and publicized. Recent field work has multiplied tonnage estimates. The question of manganese production from these rocks, as has been repeatedly emphasized by this geologist representing the Maine Development Commission, hinges upon solving the difficult metallurgical problems of economically extracting the manganese from its combinations with other elements. This is a laboratory and not a field problem.

Another metal, copper, is in keen demand. In the Blue Hill area copper is known to exist, and was produced as recently as 1918. It is possible that more ore exists in the region than is now known. If more ore can be discovered, the district, as other long-abandoned copper districts in the nation have been, may be revived. The Vermont copper district is a local illustration.

In several widely spread granite intrusions molybdenite is found here. At Cooper a small mine was developed. None, at present appear economic, but the possibility of finding a workable concentration cannot be wholly discounted. Streams that have small trout may yield larger ones. Tungsten is another metal that may be present. Although high grade prospects have not been turned up, geologically there is a possibility that discoveries may be made. (See paper on tungsten, this report.)

In the feldspar bearing rocks, the pegmatites, occur mica, beryl, spodumene, lepidolite, and rare element minerals. These are, to be sure, sparsely and sporadically present. The developments of advanced techniques in feldspar production may ultimately carry with it increased minor production of these minerals as byproducts.

The current short supply of sulfur is of particular concern to us here in Maine because of our paper industry. It is well known that a huge body of iron sulfide exists at Katahdin Iron Works. This is a low grade ore of sulfur, and it is perhaps the largest sulfide deposit in the United States east of the Mississippi River. It seems assured that this will ultimately be developed. Again on the principle that where one fish has been caught others similar may lurk, the Maine Geological Survey has actively sponsored a federal cooperative survey of the region. Preliminary results are now available. In any event, sooner or later, production of sulfur will be added to Maine's list.

Further I do not discount the probability that materials not now used commercially will become commercial, and that new techniques for improving low quality but abundant materials will increase production. As examples, I cite the possibility of expanded use of rocks as plant nutrient sources, as discussed in one of our annual reports — a discussion, incidentally, that has aroused more interest on the Pacific Coast than it has in Maine. Another example is the separation of sillimanite (used in high temperature ceramics) from its host rock. A third example, the production of light-weight concrete aggregate from expanded clays or rock could be cited, but to be brief, technological advances following the trend of the mineral industries will eventually result in increased mineral output.

The recent discovery of important ore bodies of lead-zinc-copper in New Brunswick gives us encouragement that we may hope to better our mineral position.

We turn now to the third question, What program will best advance our mineral position? The answer is obvious. More work. *First* we need to know more of the fundamental or basic geology of the region. In a region as complex as New England, geologically as well as otherwise, more information on lithology, structure, stratigraphy, and metamorphism is fundamental. *Secondly,* we need to apply new methods in field exploration. We are living in a day of applied science. More and more is it recognized that no discipline is self contained. Physics and chemistry no longer know their mutual boundaries, and just so is geological exploration becoming both more geophysical and geochemical. New techniques of exploration open new possibilities. To illustrate: in the Blue Hill area a score or more copper prospects have long been known, and have been more or less explored. One in particular, the Douglas Mine, proved profitable. Perhaps two percent of the area has bed rock exposed. The rest is covered by soil. Is it possible that only a portion of the copper prospects have been discovered by surface methods and the very limited drilling? I think so. Geophysical and/or geochemical techniques might discover favorable spots hidden beneath the cover that have not yet been adequately explored. Such techniques are not substitutes for leg work, nor for the drill, but they serve to pinpoint areas where intensive work may be rationally concentrated. These methods are expensive, and they do not put mineral deposits into the ground where none exist.

Thirdly we need to push laboratory work on the beneficiation upgrading of low grade ores. We need to find out how to separate the desirable from the undesirable economically, efficiently, and on a large scale. We need to develop new uses for presently produced minerals, and to discover uses for minerals not now valuable.

In short, a threefold program appears to me to be the rational approach to enlarging the mineral output of Maine.

1. Gather more basic geological data, rapidly and energetically.
2. Apply the most modern techniques in the field.
3. Prosecute intensive laboratory research on beneficiation and use of mineral resources.

Perhaps the tie-in with the three generalizations made at the beginning of this discussion on the national mineral trends and needs is now apparent.

Maine has some large deposits not presently economic, but which will become so if and when economic recovery of contained values is possible. The trend of the industry is in this direction of use. Manganese is but one example of this category. And Maine, also, has certain minerals of critical or strategic importance; manganese, mica, beryllium and sulfur are examples.

In my first "Report of the State Geologist", March 1, 1943, I quoted Dr. M. M. Leighton:

"The development of the natural resources of the State and of the Nation, and likewise their conservation, is dependent upon a knowledge of what those resources are, how best they can be recovered, and for what they can be used. . . . The more perfect and thorough this knowledge, the greater will be the development of a region and the sounder will be the basis for wise and practicable measures. . . ."

In this first report and in subsequent reports, a program was explicitly set forth:

1. Service to landowners and prospectors through identification of rocks and minerals and examination of prospects where justified.
2. Exploration and mapping of areas that have economic prospects for mineral development.
3. Laboratory research directed towards the discovery of new or improved techniques in separating the worthless from the valuable, or to the development of new uses for materials present in abundance.
4. Dissemination of information through publication of results of field and laboratory research.

I take it that these are the principal objectives of any state or federal geological survey. This is the program, approved by the Maine Development Commission, that has been followed as effectively as possible within the limits of financial means and personnel, handicapped by war time conditions during the war years.

In following this program we have entered into cooperative agreements and projects with the federal survey, have subsidized through publication some graduate student thesis investigations, and have used staff members of several colleges and universities. Many of the youngsters who have served an apprenticeship in this program have gone on into responsible positions in industry.

We have made investigations of: andalusite, asbestos, beryl, clay, copper, feldspar, gold, granite, graphite, grinding pebbles, ground water, limestone, manganese, mica, molybdenite, peat, pyrite, pyrrhotite, scheelite, sillimanite, slate, spodumene, uranium, as well as certain regional studies, as that of the

Blue Hill area, shore areas of clam production, Rumford, and others, together with aerial surveys of selected parts of the state. Our work on asbestos for example has produced sufficient findings to induce one of the largest mining companies in the United States to plan and carry out a large scale investigation of this possibility, and the prospects for development are contingent on discovering a large enough tonnage by a drilling program now under way.

We are living in a technical age, with advances in indirect techniques; both geochemical and geophysical aids must be brought to bear in economic analysis of an area. Hence our fieldwork must not only be channelled into favorable areas, but must include modern techniques. These methods call for both equipment and staff.

I would like to warn, as I have previously, that any illusion of doing up the job once and for all in making a geological survey in five, ten, or twenty-five years is foolishness. A survey made ten years ago would have neglected the sources of atomic energy as now needed. New uses for minerals, and uses for minerals not now used are the inevitable results of technical progress.

I would like to warn, as I have previously, also, that mineral deposits were deposited and distributed by nature and are not bought by legislative appropriation, however generous. We can only try to find what is present.

In conclusion I would say that there is no divining rod, nor clairvoyance, nor pious hope nor fatuous faith that will yield us riches. New England is not a treasure house of fabulous bonanzas of mineral wealth where the casual but lucky novice or farmer can be relied upon to bring us a regional prosperity based on minerals. On the contrary, the task is difficult, and will be costly; progress will be slow, and only achieved by use of the most modern applications of science. Irresponsible promotion and ballyhoo drain off wealth rather than create it.

LIMESTONE INVESTIGATION, 1953-54

by

HENRY W. ALLEN

INTRODUCTION

During the summers of 1953 and 1954 field investigation of limestone occurrences in Maine was continued. The 1953 season started with a detailed study of a limestone belt at North Appleton. Other limestone occurrences in Freedom, Whitefield, Brunswick and Phippsburg were studied during the field season. During the field season of 1954 numerous limestone localities were visited. Among these were localities at Dover-Foxcroft, Sebec, Atkinson, St. Albans, Athens, Harmony, Starks, Norridgewock, Vienna, Mt. Vernon, Standish, Gorham and Lincolnville. These locations are indicated on the index map.

Investigation of the limestone occurrences consisted of studying the extent and character of the limestones, sampling and evaluating the rock in terms of use. A limited number of representative samples were selected for partial chemical analysis. Lime (CaO), magnesia (MgO) and silica (SiO_2) determinations have been made on the selected samples. The able assistance of Mr. F. X. Groselle during the 1953 season and of Mr. W. B. Krueger during the 1954 season in this work is acknowledged.

The classification for limestones used in this report was used by the author in an earlier report (Allen 1953)[1]: (1) *High-calcium limestone* for limestone or metamorphosed limestone containing more than 92 per cent $CaCO_3$ (equivalent to 51.5 per cent CaO) and less than five per cent magnesia (MgO); (2) *calcium limestone* for limestone or metamorphosed limestone containing 85-92 per cent $CaCO_3$ (47.6-51.5 per cent CaO equivalent) and less than five per cent MgO; (3) *low calcium limestone* for limestone and metamorphosed limestone containing less than 85 per cent $CaCO_3$ (47.6 per cent CaO equivalent) and less than five per cent MgO; (4) *magnesium limestone* for a limestone or a metamorphosed limestone with from five to ten per cent MgO; (5) *dolomitic limestone* for a limestone or metamorphosed limestone with an excess of ten per cent MgO; but less than a 1:1 MgO: CaO ratio; (6) *dolomite* for a limestone or metamorphosed limestone if the MgO: CaO ratio is about 1:1.

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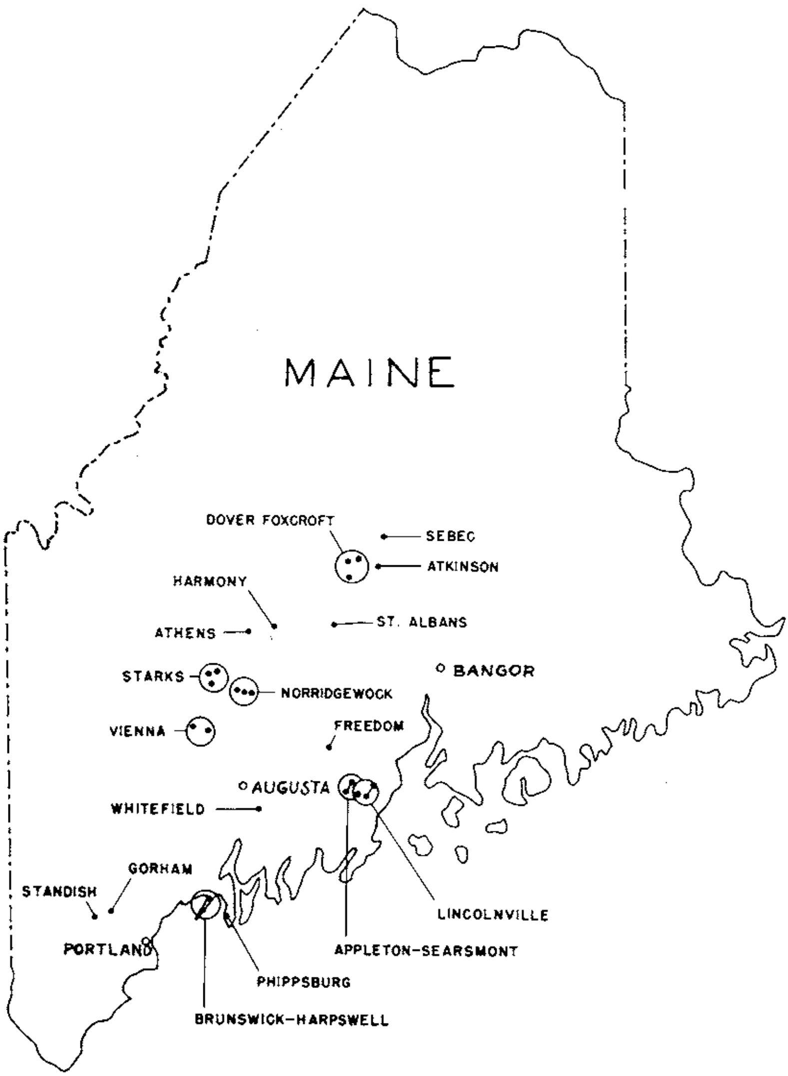
[1] Allen, H. W. (1953), "Progress Report of Limestone Survey, Knox County," *Report of the State Geologist* 1951-1952, Maine Geological Survey, pp. 11-12.



INDEX MAP OF LIMESTONE LOCALITIES

For a summary of limestone uses the reader is referred to the previous survey report (Allen 1953)[2] in which several important uses for limestone are discussed.

NORTH APPLETON LIMESTONE BELT

Location and Size

A study of the old abandoned quarries and other available exposures indicate that the North Appleton Limestone Belt generally parallels the St. George River for a distance of at least three miles in the towns of Appleton and Searsmont, Knox and Waldo counties respectively (Belfast 1/62,500). The community of North Appleton is located midway along the northwestern side of the belt (see Map at end of report). Its maximum width occurs near North Appleton where it is believed to be at least 600 feet. To the northeast and to the southwest the belt narrows as this folded belt plunges out in those directions.

Plane table mapping on a scale of one inch to one-hundred feet on the Pifster property southwest of the North Appleton bridge (see Map at end of report) revealed sixteen shallow quarries (abandoned) within an area of thick cedar growth. Trees up to a diameter of fourteen inches are now growing in these quarries. The average depth of the quarries is ten to fifteen feet with a maximum of twenty-five feet recorded in the case of Quarry O.

Lime was last burned on a small scale in the area about 1893 by a Mr. Hall. The old kiln is located 1.7 miles northeast of Gushees Corner.

Rock Description

The character of the rock varies considerably from quarry to quarry and in fact from one part of a quarry to another. Some fifty oriented samples were collected from the quarries on the Pifster property with additional samples taken from quarries and exposures in other parts of the belt.

In general the rock is finely crystalline " limestone " which is light bluish-gray in color. The magnesia (MgO) content varies from about one per cent to over 20 per cent. Dolomitic " limestone " (MgO above 10%) is interbedded with magnesium-bearing " limestone " (5-10% MgO) and with high calcium and calcium " limestones ". In places, highly crenulated bedding gives the " limestone " a decidedly mottled appearance. The dolomitic " limestone " as a rule is very fine grained, light bluish-gray in color, with narrow criss-crossing dolomite-calcite veins. Radiating crystals of tremolite of various sizes are common in the dolomitic " limestone ". Pyrite is a minor accessory

[2] Allen, H. W. (1953), op. cit., pp. 17-24.

throughout the belt occurring in small cubes in amounts ranging from a trace to approximately one per cent.

In contact with, and stratigraphically above, the " limestone " there is a light brownish-gray fine grained mica-quartz which contains occasional quartzite and calcareous interbeds.

Numerous narrow siliceous interbeds were noted across the belt, especially in the quarry walls. Obviously these interbeds had much to do with controlling the width of many of the quarries. Near the contact of the limestone belt in magnesium-bearing " limestone " several metamorphosed arsenopyrite-bearing chert beds, one to six inches wide, make good marker horizons.

Structure

Structurally the " limestone " in the North Appleton limestone belt appears to lie in an eroded anticlinorium. This folded belt is nearly isoclinal, vertical to slightly overturned to the northwest, plunging both to the northeast and southwest. Each of the sixteen quarries on the Pifster property seems to be located on or near the nose of a minor plunging fold within the anticlinorium.

A study of the distribution of quarries and the structure symbols plotted on the accompanying map suggests an en echelon arrangement of quarries converging toward the southwest (see Map at back of report). It is believed, however, that the quarryless area between the two lines of quarries is underlain by " limestone " in a similar occurrence to that in the quarry areas. Although fold axes within the mapped area were observed to be plunging both northeast and southwest, strong southwest plunges predominate. Since the mapped area is somewhat southwest of center of the anticlinorium belt (doubly plunging), and since the quarries have been excavated along the fold axes of minor folds, convergence of the two lines of quarries to the southwest is normal.

The narrow siliceous layers that have dictated the position of many quarry walls are commonly mica schists similar to the schist noted at the boundaries of the belt. In addition, occasional siliceous layers are found interbedded with " limestone " within the quarry limits. Two possibilities as to the nature of the occurrence of the original limestone formation are suggested: (1) the original limestone formation before folding and metamorphism was very thin (perhaps less than fifty feet thick) with the conformable siliceous beds now appearing in the quarry walls due to repetition by folding of the contacting siliceous layers; and (2) the limestone formation had a thickness in excess of 100 feet and contained many thin interbeds of arenaceous and argillaceous sediment and these beds have been repeated by folding as in (1).

It is impossible to determine the exact thickness of the original limestone formation, but it is believed on the basis of field observations and studies of similarly folded limestone belts that the original limestone formation was in excess of 100 feet thick. The fact that " limestones " of varying compositions are interbedded and are repeated by folding across the belt together with siliceous layers, points to an original formation that was formed as a result of deposition during a time of rapidly changing conditions. Highly dolomitic " limestone " conformably interbedded with high calcium " limestone " suggests that dolomitization took place before consolidation.

Economic Geology

Due to the complexity of the folding, it is very difficult without drill core information to delimit the four main rock types that are represented by samples in Table 1; that is *high-calcium, calcium, magnesium* and *dolomitic* " limestones ". Analyses can only serve to show chemical variations.

The silica content of the " limestone " averages something over 2 per cent but in many the silica falls below 1 per cent. In addition, thin siliceous beds scattered through the sequence would raise the average or bulk silica content as a whole. It is believed, based on the chemical analyses and field observations, the MgO content would average 5 per cent or more. Since there apparently has been much minor folding, extensive quarrying would require close chemical control to insure recovery of a certain grade of rock.

At the present status of the investigation, agricultural limestone seems to be the best possibility for areas of magnesium and dolomitic rock.

The rock in the Maygog quarry to the northeast as represented by sample L-53-BeE3-1 appears to be best suited also, for agricultural purposes. The MgO content of this sample is 11.78 per cent.

Limestone Occurrence in Freedom, Maine

A reported " limestone " occurrence one-quarter mile west-southwest of Thurstons Corner, Freedom (Liberty 1/62,500) was visited on July 31, 1953.

Fine to medium grained whitish-gray magnesium-bearing marble (5-10% MgO) has been quarried from an area 50 feet long (along the strike) by 25 feet wide as late as 1890. The quarry is now over half-filled with cedar slash which made determination of its actual depth very difficult. However, it is safe to say that the quarry never was much deeper than 20 feet. The " limestone " zone appears to be not more than 30-35 feet wide and to occupy a position on a northeast plunging anticline. The limestone plunges under a thinly banded quartz and biotite gneiss.

Field work revealed no other exposures of " limestone ". It is believed that the limestone originally occurred as a thin lens or bed between clastic sedimentary layers and has subsequently become metamorphosed and folded.

Limestone Occurrence in Whitefield, Maine

Field reconnaissance on August 3-4, 1953 in the Whitefield-Wiscasset area (Wiscasset 1/62,500) revealed no additional exposures of limestone other than the one known locality on the Elmer Heath farm 1.8 miles northeast of Whitefield village. However, low lime content rock known as lime-silicate gneiss was observed in the Newcastle area.

Two or three narrow beds or lenses of marble, varying from one to two feet wide have been quarried on the Heath farm in the distant past. The marble is a whitish-gray fine grained rock with a low magnesia content. It occurs in biotite quartz gneiss.

On the basis of present knowledge, the marble at this locality is believed to be of no economic value.

Brunswick Limestone Belt, Brunswick, Maine

Several days were spent studying the narrow belt of marble in the so-called Brunswick limestone belt along the new site of highway 24 south of Cooks Corner and related formations in the area.

The marble can be followed as a row of long narrow guts extending from the Clara Coombs place (1.4 miles south of Cooks Corner) at the edge of the Brunswick sand plain generally south for a distance of 1.5 to 2 miles.

The marble is a high calcium coarse grained white rock with occasional thin seams of mica near the contacts. It occurs as a bed varying between 7 and 25 feet wide but averaging only about 10 feet wide. Some of the abandoned quarries have a depth of some twenty-five feet.

Mapping of structures of the marble and contacting formations suggest that the marble along the Brunswick belt crops out on the western limb of a westerly overturned anticline. The dips of strata vary from 45 to 70 degrees to the east. Stratigraphically above (toward the west) the marble grades into a quartz-muscovite-biotite schist. Stratigraphically below (to the east) is a prominent amphibolite which serves as a good marker horizon along with the marble. A prominent fracture cleavage appears to be parallel to the axial planes of the folds and therefore usable in the determination of structure and sequence. In places the marble has been cut by granite pegmatite dikes.

Due to the narrowness of the marble formation, it would seem economically prohibitive to quarry the old abandoned quarries to greater depth or to exploit short unquarried areas between the old quarries. The rock has an appearance and texture which lends itself for use as a building stone. For chemical analyses of this rock see Table 1, sample L-53-B5A6-1.

Phippsburg Limestone Occurrence

A "limestone" occurrence 0.6 miles southwest of top of Fuller Mountain at the northeastern end of the Basin on old Colby farm was revisited. A quarry face of approximately 100 feet long in a north-south direction and about 10 feet high revealed a medium grained whitish-gray marble alternating with thin light bluish-gray layers (banding is parallel to bedding).

The marble is directly overlain by fine grained light greenish-gray diopside (?) bearing quartzite. Contact shows alternation of lime silicate layers and small lenses of marble up to a foot in width.

The structure of the rock underlying the peninsula on which the marble crops out appears to be a gently southwesterly plunging anticline. The sequence of strata shown on this anticline are:

4. garnet-quartz-biotite and garnet-biotite-quartz schist
3. diopside (?) - bearing quartzite
2. marble
1. amphibolite

In retrospect this is a similar sequence to that determined at Brunswick several miles to the west. In all probability the marble of the areas is equivalent. Sample L-53-B8H4-1 gives an analysis very close to that of sample L-53-B5A6-1 from Brunswick.

The Phippsburg area does not hold much promise as a source of "limestone" due to the apparent thinness of the marble and the much folded structure.

Limestone Occurrences in Dover-Foxcroft, Maine

Three limestone occurrences were visited in the town of Dover-Foxcroft. Two small, long-abandoned quarries were located on the Foss and Weston farms slightly more than a mile north of Dover-Foxcroft village. These quarries lie 0.25 and 0.9 miles respectively east of the Sebec Lake Road. The third occurrence of limestone is located on the downstream side of the Piscataquis River Falls at the east end of the village.

The Foss and Weston quarries appear to lie in the same belt which has a strike of N 75 degrees E. They are separated by a distance of 0.65 miles. The limestone belt coincides with a topographic low east of the Sebec Lake Road.

A slightly bluish medium gray, pyritiferous, thin-bedded, shaly crystalline limestone crops out in a debris filled quarry on the Foss place. Not more than twenty-five feet of width is present at this place. The limestone appears to be a member of a calcareous shale and interbedded quartzite formation. Bedding is much crumpled and cut by a foliation. Local legend claims that about 1880 the rock from the Foss quarry was carted to a railroad for shipment to the then active Katahdin Iron Works.

The Weston quarry is located in woods about one-half mile north-northeast of farm buildings. The small quarry is 15-20 feet deep and has a width of about 25 feet across the strike of the strata. Nearby is an old kiln 10 feet by 10 feet by 10 feet (inside dimensions) where the limestone was burned for lime.

The rock in this quarry appears to be similar to that of the Foss quarry. On the south side of the quarry the shaly limestone grades into calcareous shale.

Sample D.F. 54-1D7-N.W. from the Weston quarry is believed to be representative of the limestone from this belt. The lime, magnesia and silica percentages are listed in Table 1.

Due to the absence of additional outcrops in the belt it is impossible to determine the amount of rock available. The apparent narrow width of the limestone member would restrict the size of the operation. The site of the Weston quarry offers the best working face.

The limestone probably would make rock wool. Since it contains only 42.80 per cent lime (equivalent to 76.5 per cent calcium carbonate) with a low magnesia content (1.95 MgO) this limestone does not meet U. S. Department of Agriculture standards as an " ag " stone. However, this rock should not be ruled out for local use as an agricultural stone as it may contain desirable elements not found in purer limestone. It should also be pointed out that in silica, lime and magnesia percentages, the limestone of this belt is not unlike the Jacksonburg cement rock of the Lehigh Valley[1]. The apparent narrow width of this limestone belt, however, no doubt will rule out cement possibilities.

The third " limestone " occurrence in Dover-Foxcroft actually shows a rock which should better be termed intercalated calcareous shale and calcareous quartzite. It is a light to medium gray pyritiferous rock where it crops out in the river and on the prominent bluff on the west side of the Piscataquis River below the falls in the eastern part of the village. Pyrite occurs as cubes

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[1] Myers, W. M. (1949), "Cement Materials," *Industrial Minerals and Rocks,* A. I. M. E., p. 165.

up to one-quarter of an inch on a side and is present in quantities from about one to five per cent. The outcrop is about 100 yards across at right angles to the strike. A quarry face of 40 to 50 feet high is possible although high water in the river would present a quarry problem. This rock has been tightly folded as suggested by many close minor drag folds with drawn out crests, a condition typical of the region. Fold axes plunge 40 degrees to the S 70 degrees W.

See Table 1 for analysis of sample D. F. 54-1D1O N.W. from the bottom middle of the river bluff. Outside of crushed rock uses, it appears that rock wool offers the best possibility for this rock.

Sebec Limestone Occurrence

Near the western tip of Maguire Hill in the town of Sebec, limestone has been quarried for a distance of 110 feet along the strike. The quarry face is 15 feet high and 40 to 50 feet wide.

The rock is medium gray, pyritiferous, shaly crystalline low-calcium limestone similar to that referred to above which occurs east of the Sebec Lake Road in Dover-Foxcroft. Repetition of strata has been caused by chevron-like minor folding.

This quarry site is not very accessible since the road leading west from Maguire Hill has been discontinued.

Reserves are unknown since there are few exposures away from the quarry site. The analysis of sample Seb 54-9D11 S.W. (see Table 1) gives a lime content of 45.45 per cent (81.2 per cent $CaCO_3$ equivalent). This is 2.65 per cent higher than rock from the Weston quarry in Dover-Foxcroft described above. As for the limestone from the Weston quarry the agricultural possibilities should be investigated even though it is a low-calcium rock. The inaccessibility probably would rule out cement as a possible use even if sufficient rock for this purpose could be blocked out. At the present state of the investigation its use for rock wool seems the most promising.

Rock from the Maguire Hill quarry has been reported as having been carted to the Katahdin Iron Works for use as a flux stone in the latter part of the nineteenth century.

Atkinson Limestone Occurrence

Approximately two and one-half miles east-northeast of East Dover on the east side of a prominent southeast bend of the Piscataquis River, intercalated calcareous shale, shaly limestone and quartzitic limestone crop out in continuous exposure over a width of 150 feet at water's edge.

The rock here is quite similar to that which crops out below the Piscataquis River falls in Dover-Foxcroft village, but appears to have a lime content which runs somewhat higher than sample D.F. 54-1D1O N.W. from Dover-Foxcroft.

A small quarry about 15 feet in diameter by six feet deep on the river bank shows where an operation for agricultural limestone was located some 20-25 years ago. Economic use of this deposit is limited.

St. Albans Limestone Occurrence

On the low bluff at the north end of Black Point on Indian Pond medium bluish-gray shaly limestone crops out. The rock appears to be quite similar to that at the falls at Dover-Foxcroft village and at Atkinson. Thin calcite seams are very common in this rock. Although no chemical analysis is available at the present time, a calcium carbonate content of between 50 and 75 per cent is estimated for this rock.

If the quality of the rock is satisfactory for certain uses, the quantity available is not great enough to support a large operation. Along the shoreline at right angle to the strike of the strata there is about 110 feet of thickness exposed. The bluff rises five to ten feet above the pond level. High water would present a quarry problem as the water level would limit the accessibility to the bluff as well as depth of operation. If the lake level was artificially lowered, lake front property would be damaged.

This rock is reported to have been quarried and burned at one time.

Athens Limestone Occurrence

In Athens village on the west side of West Branch Stream at the bridge, thinly interbanded biotite-quartz crystalline limestone and calcareous biotite quartzite is exposed. The former tend to be bluish to medium gray in color while the latter bands are brownish to medium gray in color. Some medium gray shaly interbeds are also present. Pyrite and cross-biotite crystals are common in certain layers. The rock approaches what has often been termed a lime silicate gneiss, but does not yet show the development of lime silicate minerals which characterize similar rock to the southwest in the Farmington area. Bedding has been much crumpled by folding. Minor folds were noted plunging 60 degrees N 35° E.

Approximately 250 feet of thickness shows across the strike of the strata along the river bank. The rock does not appear to be suitable for agricultural or industrial purposes with the possible exception of rock wool. The calcium carbonate content may average slightly above 50 per cent. No chemical analyses are available at the present time.

Harmony Limestone Occurrence

"Limestone", very similar to that which crops out at Athens village, is exposed along Higgins Brook at Harmony village. The rock is well-exposed north of Highway 150 bridge for 300 feet across the strike of the strata. As at Athens the beds are much crumpled. Bedding thicknesses vary from one-half inch to six inches, but are mostly under one inch. Quartzitic interbeds along with parallel quartz stringers show prominent pinch and swell structure. Minor fold axes plunge 65° in S 30° W.

No chemical analyses are available. However, the average calcium carbonate content appears to be far below 75 per cent. Rock wool possibilities should be considered for this rock.

Starks Limestone Occurrences

Three limestone occurrences were visited in the town of Starks. Two of these were quarried to a certain extent many years ago.

Probably the most important occurrence of the three is on the abandoned Taylor farm approximately three miles northeast of Starks village. Here a canoe-shaped quarry 100 feet long (along the strike) by 25 feet wide marks where limestone was last quarried and burned for lime about 1875. The quarry area is now overgrown by trees, and the quarry is located about one-half mile east of the so-called "back road to Madison".

The limestone is finely crystalline rock, somewhat shaly, and is medium gray in color. Bedding is much folded. Lack of exposures outside of the quarry makes it impossible to determine the width of the good limestone zone. No contacts were observed but the limestone probably occurs in contact to the northwest with calcareous quartzite known to be exposed near road mentioned above.

According to the analysis of sample Ans 54-7F11 S. E. (1) (see Table I) the CaO content is 44.10 per cent (equivalent to 79 per cent $CaCO_3$). Although there is a high silica content (12.60 per cent) and a MgO content of only 1.77 per cent, the agricultural possibilities of this rock should be investigated. However, since the reserves are unknown investigation of quantity must precede any plans for use.

A second limestone occurrence in Starks is on the so-called Charles Fletcher place approximately 0.6 miles south of the road junction 1.3 miles east of Starks village. In general the rock is medium gray in color and finely crystalline. It consists of calcareous mica schist and intercalated quartz-bearing micaceous limestone. The $CaCO_3$ content appears to be below 50 per cent except in places where calcite has been segregated out into cream colored narrow lenses associated with quartz. To the east the rock is similar in color but occurs as a non-calcareous micaceous quartzite and fine grained quartz-mica schist. Chevron-shaped sheared out minor folds are abundant indicating that there is much repetition across the strike of the stata.

Overburden over the calcareous zone is quite thin as a rule. Although it was impossible to determine the exact width of the calcareous zone, a working width of at least 25 feet across the strike is possible. Traced to the northeast along the strike a width of 100 feet for the calcareous zone seems to be present. The calcareous zone can be followed to the northeast for several hundred feet along a ridge. Rock was once quarried from a small hole at site of present farm spring. It would appear that the rock may have value as a source of rock wool.

Limestone very similar to that described immediately above was observed in a road cut on the east side of Highway 43, 0.5 miles south of the Anson-Starks town line. Interbedded thin-bedded calcareous phyllite and micaceous crystalline limestone, medium gray in color, crops out over a width of 30 feet across the strike of the strata near top of hill. Many narrow quartz-calcite stringers and pods are present. The average $CaCO_3$ content may be about 50 per cent or slightly less, although no chemical analyses are available to check this.

Rock wool possibilities should be considered for the rock at this locality.

Norridgewock Limestone Occurrence

Limestone was observed in exposures in several places along Route 201A and the Maine Central Railroad on the northeastern side of the Kennebec River northwest of Norridgewock village up to a distance of two and one-half miles.

The best quality rock was seen and sampled along the northeastern side of the highway 0.5 miles northwest of the Kennebec River bridge. Medium gray, finely crystalline limestone of shaly bedded character is exposed continuously over a distance of 30 feet across the strike of the strata. Indications that there is at least 50 feet of width. Thin siliceous and/or micaceous beds are numerous. In places good calcium limestone beds up to three inches thick are present.

A quarry face of approximately 15 feet above road level could be developed. This height would be increased as the operation moved toward the northeast. Since contacts were not seen, the total width of the limestone outcrop is not known. Small drag folds indicate a position on the southeast limb of a slightly overturned anticline.

Sample Nor 54-3C4-S.E. (2) has been analyzed (see Table 1). The analyses of the rock here is almost identical with that from the Weston quarry in Dover-Foxcroft and may be a part of the same formation. The limestone at this locality apparently would qualify for the same uses as that at the Weston quarry. Especially agricultural and rock wool possibilities should be investigated.

Of several other exposures noted along the highway and railroad rights of way, the most important are two prominent railroad cuts. One is 0.9 miles northwest of the Kennebec River highway bridge and the other is one and three-quarter miles northwest of the bridge.

The former location is adjacent to the Knight Place. An abandoned narrow quarry, 50 feet long by 10 feet high, about ten feet higher than the roadbed near the east end of exposures shows a " limestone " that was once utilized locally. A few years ago this rock was again considered to be of economic importance and a lime company formed. Apparently the limestone did not prove out for whatever use or uses that were being considered at the time.

Rock is exposed discontinuously along the hill slope over a distance of about 100 feet along the right of way. A hill rises some 90 feet above the tracks to the east. The rock at this location is a shaly bedded, siliceous, crystalline limestone intercalated with thinbedded calcareous quartzite and calcareous schist. In general the rock is medium gray in color with somewhat brownish quartzitic layers due to the presence of biotite. Presence of light greenish-gray crystals in some of the siliceous layers suggest the development of lime silicate minerals. Contorted narrow quartz-calcite stringers are common.

The average lime content seems to be somewhat lower than that represented by the analysis of sample Nor 54 3C4 S.E. (2) (refer to Table 1). Status of investigations to date indicate that rock wool possibilities seem best for the rock at this location. The railroad bluff offers an excellent opportunity for a quarry location.

A second railroad cut is located one and three-quarters miles northwest of the Kennebec River bridge. The rock is exposed as a bluff on the railroad right of way, rising about twenty feet above the road bed and extending in almost continuous exposure for a distance of approximately 110 feet along the railroad. There seems little doubt that the limestone here occurs as a part of the same formation as other limestone occurrences in the immediate vicinity.

Rock similar to that at the first railroad cut described above is also present here. Biotite crystals up to one-half mm across tend to parallel the foliation. Irregular quartz-calcite stringers are abundant. Limestone beds are mostly less than one inch thick. Change of dip of the strata across the outcrop suggest tight minor folding.

As at the other railroad location above, the rock is believed to be of a composition that should lend itself to the manufacture of rock wool. No chemical analyses are available at the present time, but on the basis of field investigations, this limestone would run somewhat lower in calcium carbonate than sample Nor 54-3C4 S.E. (2).

Vienna Limestone Occurrence

Near the western boundary of Vienna, approximately one mile west southwest of the North Vienna Church and 0.2 miles east of road, limestone is exposed on the N. A. Green place (now believed to be owned by a Lewiston resident).

Micaceous-diopsidic marble has been extensively quarried here. Fifty-year old stumps of spruce trees that grew on the quarry dumps (trees have been cut at least four or five years) suggest the quarrying operation goes back to at least the latter part of the nineteenth century.

The rock is typically medium grained granular textured "limestone" (marble) consisting of alternating bands of diopsidic-bearing whitish-gray marble and finer grained brownish medium gray biotitic marble. This rock is a phase of the lime silicate gneiss formation which is known to be widely occurring throughout the southern and western parts of the state.

A series of quarries and prospect pits across the strike indicate a width of at least 100 feet. Along the strike the limestone can be traced for approximately 900 feet along the side of a ridge. The formation has been intruded by pegmatite which forms the top of the ridge. Small pegmatite dikes were also observed cutting the limestone.

Sample Far 54-9C6 S.E. (1) is believed to be fairly representative of the limestone. Analysis of this sample shown in Table 1 gives a lime content of 45.84 per cent (equivalent to 82 per cent $CaCO_3$), magnesia as 2.54 per cent and silica as 8.34 per cent. The fact that this is a somewhat impure limestone does not eliminate the rock as a soil additive. Keller (1951)[1] points out that certain limestones now rejected because of impurities possibly should be prized because of those very impurities. Common inorganic as well as trace elements (micro-nutrients) may be available in a desirable form.

[1] Keller, W. D. (1951), Industrial Minerals and Rocks as Plant Nutrient Sources, *Report of the State Geologist* 1949-1950, Maine Geological Survey, p. 21.

The largest of the quarries is about 150 feet long averaging 15 to 25 feet wide with a maximum width of 35 feet. The maximum depth is about 20 feet. No doubt this and adjacent quarries could be worked to much greater depths. Core drilling is necessary to further evaluate this locality.

Mt. Vernon Limestone Occurrence

Along the middle eastern shore of Flying Pond, 1.2 miles north of Mt. Vernon village, " limestone " similar to that described above from Vienna crops out as a forty-foot high bluff. The rock is light greenish-gray diopsidic marble interlayered with light to medium gray biotitic marble. There is a marked development of diopside at this locality. Many sheared-out quartz nodules are present. Discontinuous exposures along the shore of the pond extend for a distance of about 100 feet. Also about 200 yards to the east on the eastern side of Highway 134, the limestone was formerly quarried from a small quarry on the Fred Moss farm and was burned for lime in a nearby kiln. The width of the outcrop in the field is twenty-five feet across the strike of the strata.

No analyses are available at the present time, but the rock is believed to be somewhat lower in lime than the Vienna rock. This rock does not seem suitable for commercial purposes outside of rock wool, but the agricultural possibilities should be investigated as pointed out above under the Vienna occurrence.

Standish Limestone Occurrence

Three small pits, now filled with debris, located in Sebago Lake Village 0.3 miles south of the southwestern corner of Lower Bay were sources of limestone burned for lime as late as 1888. The limestone crops out in these three pits on the so-called Bird Place. The rock is a calcareous quartzite (lime silicate gneiss), light greenish-gray in color. No good marble beds are visible. The $CaCO_3$ content is probably less than 50 per cent.

On the basis of field observation this " limestone " occurrence appears to have little economic value.

Gorham Limestone Occurrence

Limestone occurs on the northwest side of Highway 95 approximately 0.4 mile southeast of Pleasant Ridge in Gorham. A shallow quarry 75 feet by 35 feet was last worked before the end of the last century. The exact depth of the quarry is unknown since water stands in it, but it is probably not more than 20 feet. The rock is a very impure crystalline limestone with interbedded calcareous schist and quartzite. It is medium gray to dark gray in color and contains much biotite and quartz.

No analyses are available, but the rock appears too siliceous to be of value except perhaps as a source of rock wool. Since the limestone crops out in the bottom of a gully, there is not a good opportunity for development of a quarry face.

Lincolnville Limestone Belt

Reconnaissance of the Lincolnville limestone belt was made in 1952 in conjunction with mapping of the Rockland and Rockport limestone belts to the southwest. During the 1954 field season this work was expanded.

Location and Size

The main Lincolnville limestone belt occupies a portion of the valley between the northern end of Mequnticook Lake and the southern end of Coleman Pond, a distance of over three miles. The general northeast-east trend reflects the strike of the limestone strata. Actually when followed to the east, the belt curves from northeast to strongly east or slightly south of east (see Map at back of report).

At no place could the exact width of the belt be determined since the limestone is exposed only in old quarries along the belt. However, in the vicinity of the Milliken quarries, approximately 0.3 mile southeast of the southeastern side of Norton Pond, some half-dozen quarries indicate a width of at least 600 feet from edge of swamp to within 450 feet of the highway. Probably a much greater width is present throughout much of this belt.

The principal quarry areas besides the Milliken quarries mentioned above, are the Don Heal quarries just west of the southern end of Coleman Pond and the Cilley quarries 600-700 feet west of the four corners 0.9 mile southeast of Lincolnville Village.

Rock Description

From available exposures in quarries along the long axis of the Lincolnville limestone belt, the limestone which has been quarried appears to be of three main types. These types from youngest to oldest are: (1) light bluish-gray, fine to medium crystalline high-calcium limestone often showing a thinly striped character; (2) a very light gray fine to medium crystalline magnesium limestone commonly with thin light brownish-gray mica-bearing bands; and (3) a light bluish-gray, fine grained crystalline dolomitic limestone. The high-calcium limestone is represented by sample L-52-22-(2) from the eastern end of the Heal quarries; the magnesium limestone by sample L-52-22(1) from the eastern end of the Heal quarries; the dolomitic limestone by L-52-21 from the northwestern most exposure in the Milliken quarry area.

It should be emphasized that what is above and below the sequence outlined was not seen since there were no exposures or drill cores available, nor was it possible to determine the true thicknesses of the various members. However, cross-bedding in the high-calcium limestone in the Milliken quarries indicate that that member is at the top of the sequence listed.

Structure

It was impossible to determine the exact nature of the structure of the Lincolnville limestone belt due to paucity of exposures. Exposures, as pointed out above, are confined to abandoned quarries along what appears to be the lone axis of the belt. The gentle dips of the strata is very striking for an area which has had as complex a tectonic history as this one. Dips are consistently to the west-northwest in the southwestern part of the belt and northwest-north in the eastern end varying between 15 and 20 degrees. Strikes average about N 35° E in the Milliken quarries nearly a mile northeast of the southwestern end of the belt. Midway along the axis of the belt in the Cilley quarry area the strike is N 70° E. Near Coleman Pond the strike is S 75° E. This variation in the regional strike no doubt reflects the major structure of the area.

Examination of the country rock on both sides of the limestone belt indicates that the same gneissic quartzite and mica-quartz schist is present on both sides as in the case of the North Appleton limestone belt approximately five and one-half miles to the northwest (refer to Map at back of report). The similarities that exist in the two belts can not go unnoticed since it suggests a parallel situation for the two occurrences. It is highly probable that as at North Appleton, the Lincolnville limestone belt occurs as a doubly plunging anticlinorium. The only minor fold axes observed were in one of the Cilley quarries. Here axes were found to be plunging a gentle 10 degrees in a S 50° W direction.

It is believed that the quarries in general have been located on the normal limbs of southeasterly overturned folds where the dips tend to be gentler than on the overturned limbs.

Economic Geology

Too few analyses have been made to evaluate the Lincolnville limestone belt. However, from the analyses along with field observations tentative conclusions can be reached. Of particular interest in the valuation is the analysis of a composite sample of many specimens from the Milliken quarries. This analysis is listed in Table 1. It appears to represent a mixture of high-calcium — calcium limestone and magnesium limestone having an average MgO content of 7.99 per cent. The silica content of 4.78 per cent appears to be somewhat higher than that of the rock from the Heal quarries.

Besides rock which averages nearly 8 per cent magnesia in the Milliken quarry area, there is dolomitic limestone below with a MgO content of nearly 20 per cent. Together these limestones seem to qualify for agricultural limestone. This rock in the Milliken area has too much magnesia to make portland cement and too much silica for chemical or metallurgical uses. Core drilling in unquarried areas or at depth may reveal rock suitable for these purposes.

Observations made in the Heal quarry area along with the two available analyses suggest that the rock there also runs too high in magnesia for portland cement. The silica content of 2 per cent or less may allow the rock to be used for chemical or metallurgical uses. It is also believed that with proper control agricultural limestone can be produced here that would meet minimum magnesia requirements of the Soil Conservation Program of the Federal Government.

Limestone was extensively quarried and burned in this area many years ago and the lime was shipped from Ducktrap Harbor to Fall River, Mass. and probably other places.

At the present time some private investigation in the form of core drilling is being carried out in the Heal quarry area. No information has been released.

It is recommended that core drilling be carried out away from the long axis of the limestone belt toward the northwest and southeast boundaries.

Additional Lincolnville Limestone Occurrence

Approximately 0.5 mile south of the southwestern corner of Moody Pond on the Thurlow farm there is a series of abandoned shallow quarries. The quarry area extends about 500 feet along the strike and 200 feet across the strike of the bedding. The largest quarry is nearly circular with a diameter of about 200 feet. No exposures of the limestone were found outside of the quarry area.

The rock is for the most part a fine to medium grained, mostly whitish-gray to light bluish-gray, stripped dolomitic crystalline limestone. Sample Bel 54-8B7 S.W. (1) has been analyzed. A MgO content of 20.30 per cent, 30.91 per cent lime (55.2 per cent calcium carbonate equivalent) and 2.12 silica was determined.

To the southeast there is a sharp contact between the limestone and apparently overlying gneissic quartzite. To the northwest across the strike over a horizontal distance of 150 feet, at least two other 8 to 10 foot zones of quartzite occur and appear to be interbedded with the limestone. An irregular shaped granite mass has intruded the limestone 100 feet south of the northeastern end of the exposures.

It would appear that this limestone occurrence which lies approximately midway between the North Appleton and Lincolnville limestone belts may correlate with them.

The rock seems to be best suited for agricultural purposes. More prospecting by core drilling is necessary to further evaluate the occurrence.

TABLE 1 — PARTIAL ANALYSIS OF LIMESTONE SAMPLES

Sample No.	SiO_2	CaO	MgO	Location
L-52-21	4.26	30.52	19.72	Edge of swamp, Milliken quarries, Lincolnville
L-52-22-(1)	2.04	43.49	9.54	Western end, Heal quarries, Lincolnville
L-52-22-(2)	1.40	53.95	1.01	Eastern end, Heal quarries, Lincolnville
L-53-B8H4-1	5.80	50.02	1.65	Abandoned quarry, Colby farm, Phippsburg
L-53-BeD4-8	1.76	53.08	1.51	Northern end quarry D, Appleton
L-53-BeD4-14	2.90	48.08	5.27	Northern end quarry M, Appleton
L-53-BeD4-16	3.40	52.00	1.57	Northwestern side quarry N, Appleton
L-53-B5A6-1	0.50	54.11	1.25	Hwy. 24, 2 miles south of Cooks Corner, Brunswick
L-53-BeD5-2	1.44	54.44	0.63	Southern end quarry A, Appleton
L-53-BeD5-10	0.58	53.67	1.71	Near southern end quarry B, Appleton
L-53-BeD5-16	4.34	49.10	3.74	Southeastern side quarry G, Appleton
L-53-BeD5-20	0.54	30.89	20.98	Northeastern side quarry I, Appleton
L-53-BeD5-26	6.90	48.78	2.73	Northern part of quarry J, Appleton
L-53-BeE3-1	1.20	41.15	11.78	Maygog quarry, Searsmont
Bel 54-8B7-S.W. (1)	2.12	30.91	20.30	Thurlow farm, Lincolnville
Nor 54-3C4-S.E. (2)	14.80	43.41	1.55	½ mile northwest Kennebec R. Bridge, Norridgewock
Far 54-9C6-S.E. (1)	8.34	45.84	2.54	N. A. Green Farm, Vienna
D.F. 54-1D7-N.W.	12.40	42.80	1.95	Abandoned quarry, Weston Farm, Dover-Foxcroft
D.F. 54-1D1O-N.W.	41.80	13.48	3.49	Below Piscataquis R. Falls, Dover-Foxcroft
Seb 54-9D11-S.W.	9.32	45.45	1.59	Maguire Hill, Sebec
Ans 54-7F11-S.E. (1)	12.60	44.10	1.77	Abandoned quarry, Taylor Farm, Starks
Composite Sample	4.78	44.96	7.99	Composite sample from Milliken quarries, Lincolnville (Al_2O_3 — 1.38%, Fe_2O_3 — 0.72%, loss on ign — 40.90%)

AIRBORNE MAGNETOMETER INVESTIGATIONS IN EASTERN MAINE

WILLIAM T. FORSYTH

INTRODUCTION

Since the discovery of vast deposits of low grade base metal deposits around Bathurst, New Brunswick, the Maine Geological Survey has been interested in examining the St. Croix River basin to determine if similar deposits existed in that region. The Survey's interest was based on a geologically similar relationship of igneous rocks to metasediments which trend from Bathurst toward the St. Croix region. Because of the large area to be covered, if the survey were to be considered anywhere near adequate, it was deemed necessary to resort to some rapid preliminary method which would disclose certain areas more suitable for ground prospecting. The method finally decided upon because of speed of coverage, comparative ease of interpretation, cost per mile, and availability was the airborne magnetometer survey.

The airborne magnetometer, developed during World War II for the purpose of detecting submarines, will react to the naturally occurring minerals magnetite (Fe_3O_4) and pyrrhotite (FeS) as well as to the ferrous metals. Since these minerals are frequently associated with more valuable base metal mineralization, they serve as indicators in a magnetic type of survey for ores. Their abundance is indicated by changes in the intensity of the magnetic field as continuously recorded by instruments within the plane which is towing the magnetometer. Because various rock types normally carry small amounts of these magnetic minerals, the magnetometer record serves also as a valuable guide in outlining the different formations and intrusives.

This particular survey was contracted to Aero Service Corporation of Philadelphia, Pa. who were pioneers in the development of this method as a tool for prospecting. The survey was carried out using a modified Gulf magnetometer towed by a twin engined Beechcraft AT - 11 at an altitude of 500 feet above the ground. Flight lines were approximately ½ mile apart and laid out in advance so that they would be approximately at right angles to regional structures. Instruments for making a continuous record of the magnetic intensity, elevation above the ground, and radiation intensity were carried within the airplane. Continuous strip photographs were taken with reference points marked periodically on all tape records so that the plane's course could be tied in with known points on U. S. Geological Survey topographic base maps. Following completion of the flying, the records were plotted on the base maps by Aero Service Corporation. The contours on the accompanying maps (Plates 2 and 5) are lines of equal magnetic intensity with peaks in the field indicating relative increase of magnetic minerals in the underlying rocks.

Before the maps have much significance as a guide to prospecting, certain facts must be known about the geology of the region; therefore, a ground party was sent into the flight areas by the Maine Geological Survey to gather information on the distribution of the various rock types. Ground work carried out in 1953 and 1954 by the writer assisted by Sewell B. Millett and John A. DeWilde consisted essentially of outlining igneous-sedimentary contacts and checking areas of anomalous magnetic pattern for possible ore mineralization.

To facilitate discussion of the geology the following report is broken down into two divisions, based upon the nomenclature given to the separate flight strips by the Aero Service Corporation, the northern flight being referred to as the Forest City Area and the southern flight as the Meddybemps Area. Because of prevailing ground conditions and more peculiar magnetic effects, more time was spent on the Meddybemps Area than on the Forest City Area, but in each region certain anomalies cannot be factually explained due to the presence of swamps and a heavy mantle of glacial drift. It is hoped however that this preliminary work will stimulate the interest of private organizations to continue geophysical investigations in the areas of unexplained magnetic anomalies.

Forest City Area

Location

The Forest City flight strip (Map) is 42 miles long and 8 miles wide, the eastern margin of which extends S 20° E from Orient to Indian Township in Aroostook and Washington Counties respectively. Parts of the strip are located on the following 15′ Series topographic quadrangles of the United States Geological Survey: Amity, Danforth, Forest, Scraggly Lake and Waite.

Topography

The configuration of the land is generally subdued and gently rolling with the exception of a few high hills around Topsfield and along the westerly side of the Chipuneticook Lakes. Most of the hills and rises show a strong linear orientation in a northwest - southeast direction, regardless of being composed of bedrock or glacial drift. This appears to be an effect produced by continental glaciation rather than bedrock control, especially in the metamorphic areas where the structural trend is to the northeast. Northwest-southeast joints in the granite may however have contributed to this linear effect. Around Topsfield the rugged topography reflects a granitic bedrock but the ridges along the boundary line lakes consist of both hornfelsic metasediments and granite. The gently rolling and swampy areas are for the most part underlain by the softer metasediments.

The average height of the land is around 450 feet in the southern half of the strip but gradually rises to about 600 feet in the north. Conspicuous hills are Peekaboo Mtn., Flagstaff Mtn., Walls Hill, Greenland Mtn., Tomah Mtn., and Farrow Mtn., which all rise to the vicinity of 1000 feet.

Drainage

Most of the minor streams flow parallel to the topographic lineation. Although the drainage density is fairly high, much of the terrain is swampy due to a combination of a thick mantle of glacial drift and shallow stream gradients. The larger streams which originate in some of the more prominent ponds and flowages have very intricate meander patterns and gradients often less than four feet per mile.

Geology

White porphyritic granite. This granite is found along the western side of the Chipuneticook Lakes and extends southeasterly in an arcuate band from Orient to Vanceboro. Its western edge is cut off by impure quartzites and phyllites which locally show the effect of contact metamorphism. The shores of many of the lakes in this region are covered by blocks of this granite averaging two feet in diameter but commonly ranging up to eight feet or more.

The rock is a medium grained white porphyritic biotite granite with well oriented phenocrysts of twinned perthitic feldspar whose length may reach two inches. Locally the phenocrysts are absent but the texture of this rock is quite similar to the groundmass of the porphyritic phase. One of the distinctive features of the granite is the presence of spherical to ellipsoidal clots of fine grained biotite, quartz, and feldspar. The clots which vary in length from 1½ to 30 inches have fuzzy contacts with the adjacent rock. The component minerals seem to be the same as in the granite but biotite is more abundant.

Quartz veins are relatively rare in this granite but several up to one foot thick were found near the crest of a hill directly west of Little Greenland Lake. A fine grained muscovite bearing aplitic phase was found on the summit of Greenland Mtn. (el. 1264 ft.). About half way down the southwest slope of the same hill an exposure of a quartz, perthite, muscovite pegmatite with crystals up to 18 inches in diameter was located but could not be outlined further because of the drift cover.

Contact of this granite with the surrounding metasediments was observed at only one place, in a pasture approximately 1000 feet west of the Bancroft School. This contact was sharp and showed no textural differences from other exposures of the non-porphyritic granite. Muscovite, however, was present in a slightly larger quantity than usual. A few one foot thick apophyses of the granite extend into the metasediments parallel to the bedding planes for distances up to eleven feet.

No ore mineralization was found in this granite and very little evidence of hydrothermal activity outside of the few quartz veins and the one pegmatite previously mentioned was observed. One fact which might be of significance is the presence of the muscovite aplite on Greenland Mtn. This rock is very similar to the molybdenite bearing granite at Cooper, Maine, which according to Wing[1], appears to have a replacement texture. The Cooper rock, however, is associated with a pink granite as are many of the other molybdenite occurrences in Maine.

Pink biotitic granite. This pink granite occupies an elliptical belt which extends northeast - southwest in the towns of Topsfield and Codyville. It continues southwesterly from East Musquash Lake but has not been delineated in that direction. High rugged topography marks the area underlain by this granite in contrast to the adjacent lowlands underlain by metasediments.

The rock is a medium grained allotriomorphic biotite granite with a somewhat variable composition, but characterized by its consistency in carrying pink perthitic feldspar. White feldspar, presumable sodic plagioclase, is present in some of the outcrops and is generally smaller in size than the pink feldspar. Grains of plagioclase sometimes show a concentric zoning and may occasionally form a partial rim about the perthite. Numerous flakes of fine biotite are found within the larger grains of plagioclase giving it a poikilitic texture. The plagioclase content of this rock is its most striking variable. A sample taken along Rt. 1 about 2¼ miles north of Topsfield Corner has a ratio of 2 parts white to 3 parts pink but that from Kane Ridge (el. 730 ft.) to the east has no white feldspar at all. Some of the pink grains however bear twinning indicative of a calcic plagioclase but the ratio is inde-

[1] Wing, L. A., (1953) Preliminary Report on Eastern Maine Granites. Report of the State Geologist, 1951-1952, p. 50. Maine Development Commission, Augusta, Maine, 1953.

terminate in the hand specimens. Insufficient field work has been accomplished to determine if a mappable zoning is present within this granite mass, but it seems to be a good possibility.

Minor amounts of iron pyrite occur as small clots ¼ to ½ inch long in a road side outcrop on Route 1, ¼ mile south of BM752. A small pegmatitic phase of this granite was exposed in a field south of the dirt road crossing Hunt Ridge, about ½ mile west of BM490. The pegmatite is less than four feet wide where exposed, appearing to be surrounded on all sides by the red granite, and consists of crystals of graphic pink perthite and quartz.

No actual contacts with the metasediments were observed, but many of the rocks closest to the granite appear to be metamorphosed to the same extent as those in a similar spatial relationship to the porphyritic granite. On the south shore of East Musquash Lake, an impure quartzite is highly epidotized and shot through with narrow quartz veins suggesting hydrothermal activity. In this location small, but larger than usual, amounts of magnetite are present.

Metasediments. Many varieties of metamorphosed sediments occur in this region but most may be collectively assembled into an equivalent of the Charlotte Group (pre-Silurian) of the Canadian Geological Survey.

These rocks consist predominantly of dark grey finely interbedded quartzites and phyllites. The frequency of bedding ranges between ½ and 1½ inches although hairline streaks occur in most of the sandy layers. Megascopically the sandy layers consist of fine grained quartz and biotite; the pitted argillaceous layers appear to carry small knots of biotite in a fine micaceous matrix. This group does not usually exhibit a well defined fissility but occasionally a phyllitic bed may be found between the quartzites. Compared to the rocks described below, these quartzites and phyllites might possibly be considered hornfelsic equivalents, because upon approaching igneous contacts the pits and spots become more abundant in conjunction with a noticeable coarsening in texture.

In the immediate vicinity of Danforth, black slaty and quartzitic sediments with occasional gritty seams were found. These rocks sometimes show a banding on the same order of magnitude as the aforementioned impure quartzites but their texture is a lot finer. A sample from an outcrop of this rock on the Bancroft road about 1½ miles north of Danforth carried what appears to be a graptolite fossil but the identification is not positive due to the degree of deformation. It is tentatively offered that these rocks are less metamorphosed equivalents of the impure quartzites exposed near the granitic contacts.

One distinctive rock type which might be valuable in a detailed structural mapping of this area is a limestone pebble conglomerate which was picked up in two localities. Both are at roadside outcrops (1) on Rt. 1, 2¾ miles south of Weston and (2) ¼ mile east of Croperly Turn. The rock is a sharpstone conglomerate consisting of a mixture of dark quartzitic fragments and more rounded limestone fragments. Boundaries between the two types are hazy and gradational with lime silicate minerals developed at the interfaces. Weathered surfaces present a pitted appearance due to the solution of the limestone.

Immediately north of the pink granite area on Rt. 1, a series of outcrops of red and grey green slates are exposed. These rocks were not recognized at any other localities near the porphyritic granite contacts. The slates have a well developed fissility which is sometimes crumpled. Variable amounts of quartz in the specimens, however, give the rock occasionally a more massive structure. These same slates occur in Brookton beneath the drift cover as indicated by cuttings which were obtained from a churn drill supposedly drilling for oil. Both the red and green varieties were present in the cuttings indicating possible interbedding.

Calcareous quartzite was observed at one locality in the village of Waite. This rock was highly fractured and contained small amounts of pyrite in association with thin calcite fracture fillings.

The general strike of the sediments is toward the northeast with dips consistently over 45° to the southeast. Local variations are probably caused by drag folding or by deflection at igneous contacts. Close folding on a small scale was observed where the railroad crosses Baskahegan Stream in Danforth. Fold axes were recorded plunging 60° to N 70° E. Cleavage is all but absent except in the slaty rocks where is appears to parallel the banding of the layered varieties, perhaps indicating close folding on a large scale.

Economic Aspects of the Area

No ore deposits are known to exist within the boundaries of this flight strip and very little evidence of mineralization was observed by the ground party. A small showing of iron oxides occurring as 1 to 1½ inch lenses was found associated with quartz veins cutting through quartzites and phyllites near Forest Station but no primary minerals were turned up in these outcrops. Several anomalies occur in the immediate vicinity of this occurrence but no further exposures of rock were found to explain their cause. A long linear anomaly is found north of Danforth cross cutting both sediments and granite and continues into Canada. Granite exposures along the strike of this anomaly have been visited but nothing was observed which might indicate its cause.

Immediately north of the pink granite area, the highest anomaly on the entire strip is found. Although apparently occurring in slates, the anomaly might be caused by a continuation of the granite at a shallow depth beneath the sediments.

Meddybemps Area

Location

The Meddybemps area lies southwest of Calais, Maine and is approximately 14 miles wide and 22 miles long in a southwesterly direction. Included within its boundaries are parts of the Big Lake, Calais, Wesley, and Gardiner Lake topographic quadrangles, (USGS). (See Fig. 1.)

Previous Work

Although no systematic mapping of this area had been done prior to this work, several writers have described certain aspects of the region, with others having done aerial mapping on surrounding quadrangles. Emmons[2], Hess[3], and Wing[4] have all examined the Cooper molybdenite mine after operations had ceased. Bastin and Williams[5] have mapped the Eastport quadrangle, and the Columbia Falls quadrangle has been mapped by Terzaghi[6]. Smith and White[7] have mapped the geology of the Perry Basin, contributing much to the dating of the rocks in that area. Alcock[8] has mapped the region around St. Stephen for the Geological Survey of Canada revealing geological situations quite similar to those occurring in the Meddybemps area.

Topography

The land within this area is low and gently rolling. Very few hills extend over 500 feet above sea level. The lowlands are generally swampy and covered with glacial drift so that most of the bedrock relations can only be inferred. The most conspicuous glacial feature on this quadrangle is the large esker delta southwest of Meddybemps Village. The delta has been a very good

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2 Emmons, W. H. (1910) Some Ore Deposits of Eastern Maine and the Milan Mine, N. H. (1914) Eastport Folio. United States Geological Survey, Bulletin 432, p. 42.

3 Hess, F. L. (1907) Some Molybdenite Deposits of Maine, Utah, and California, U. S. Geological Survey Bull. 340, p. 234-235.

4 Wing, L. A. (1953) op. cit., p. 47-51.

5 Bastin, E. S. & Williams, H. S. (1914) Eastport Folio. United States Geological Survey, Geological Atlas, Folio 192.

6 Terzaghi, R. D. (1946) Petrology of the Columbia Falls Quadrangle, Maine. Maine Geological Survey Bull. 3.

7 Smith, G. O. & White, D. (1905) The Geology of the Perry Basin, U. S. Geological Survey, Prof. Paper No. 35.

8 Alcock, F. J. (1946) Preliminary Map of St. Stephen, New Brunswick, Geological Survey of Canada, Paper 46-2.

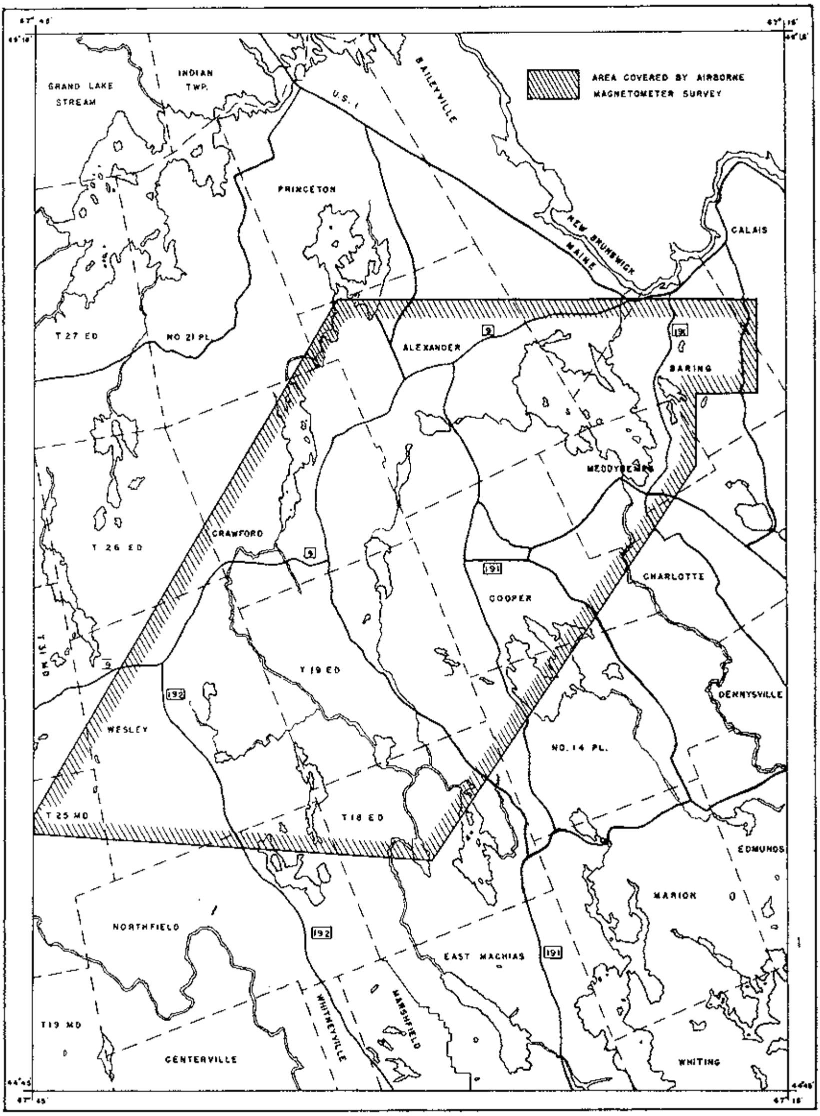


Fig. 1. Area covered by airborne magnetometer.

source of highway gravel and is still being used as such. The adjoining esker is composed of many disconnected segments but may be traced northwesterly on the Calais quadrangle for a distance of 15 miles. Another conspicuous segmented esker extends from the southern end of Love Lake to Fulton Lake, a distance of 12 miles where it appears to terminate in a pitted outwash plain. Other outwash deposits cover large areas around Seavey Lake and Little Seavey Lake.

The St. Croix River which forms the natural boundary between Maine and New Brunswick from Passamaquoddy Bay to Vanceboro is the largest stream in the area. The largest body of water is Meddybemps Lake which drains into the Dennys River at the south and into the St. Croix River to the north. This northern outlet is caused by artificial damming of the lake at the Dennys River outlet.

Meddybemps Heath, a flat swampy plain generally less than 20 feet above the lake level, has the appearance of being part of the former lake bottom and the valley presently occupied by Wapsconahegan Brook seems to have afforded connection with the St. Croix River in the past.

Geology

Metasediments. Many varieties of metasediment occur within the belt at the westerly side of the flight strip, but with the exception of a band of grey phyllite around Crawford Village and some chloritic phyllite on Old Stream near the intersection of Joe Hill Brook, they are impure quartzites with variable amounts of originally argillaceous material.

Rocks belonging to the Dark Argillite division of the Charlotte Group (Pre-Silurian, Canadian Geological Survey) occur in the northern part of the area. These rocks are dark grey impure quartzites with some spotted phyllitic layers. In many places the quartzites carry a heavy iron staining which is caused by the oxidation of small disseminated particles of iron sulfide. Occasionally minor concentrations of this mineral are observed along hairline joints.

Megascopically the rocks consist of quartzitic layers containing minor amounts of randomly oriented muscovite and biotite, alternating with other quartzitic bands containing numerous micaceous clots, ranging in size from 1/16 to 3/16 inches. Where the interlayers are more phyllitic, the clots are generally smaller and lie flat in the plane of foliation.

No direct tracing of the Pale Argillite division of the Charlotte Group was made due to the intervening strip between this area and the Canadian boundary. The light grey slate around Crawford Village, however, might possibly be associated with rocks of that division because of its structural relations and physical properties.

This slate is closely laminated but shows no definite bedding plane. The foliation is gently undulatory, occasionally exhibiting a few fine wrinkles. Locally the rock contains enough magnetite to cause a deflection in a compass needle. Barren quartz veins up to thirty inches thick occur quite abundantly in this rock parallel to or slightly cross-cutting the foliation.

The remaining metasedimentary types to be described below are not assigned to any definite stratigraphic position because the writer does not believe that such a disposition is justified without additional field work.

One of the more unusual metasedimentary areas occurs in the southwest corner of the Calais quadrangle. These rocks are a mixture of quartzitic schists and gneisses with a higher mica content than usual. Locally as on the summit of Breakneck Mountain, they contain small clots of tabular to acicular sillimanite with many specular hematite inclusions. The rock in this roughly triangular area also shows a somewhat heavier iron staining, and frequently float blocks of pyritiferous quartz veins are found. The appearance of the sillimanite in these rocks suggest that they might be part of a contact metamorphic aureole underlain at a shallow depth by the adjacent granites.

The rocks around the village of Wesley are mixtures of phyllites, sedimentary gneisses, and micaceous quartzites. Occasionally thin layers containing 1/8 inch chiastolite grains may be found interbedded with the quartzites.

On Old Stream, chloritic phyllite occurs interlayered with pale green quartzites. Small amounts of magnetite and pyrite can be found in some of the outcrops but these rocks lack the iron staining so common in the aforementioned areas.

Many outcrops of a massive green quartzite are found between Richardson Brook and Northern Stream in Township 19. This rock assumes a black color near the igneous contact and frequently is cut by granitic stringers.

The structure of the metamorphic rocks is very complex as indicated by the numerous undulations in the dip and strikes. The smaller folds vary from gentle flexures to isoclinal drags. Strikes are mostly to the northeast with dips from 45° - 80° to the northwest or southeast. Strong deflections from this trend are present, especially near igneous contacts. A persistent northerly trend may be observed on the magnetic map in the slate area on the westerly side of the flight strip.

Igneous Rocks. Plutonic igneous rocks predominate in the eastern half of the region under discussion, but small amounts of finer grained volcanic or hypabyssal types are also present. The plutonic types which are by far the most abundant consist of a series of diorite and gabbroic bodies, several textural and mineralogical varieties of granite, and a granite - diorite intrusion breccia. The finer grained porphyritic rocks have only been observed in isolated outcrops, therefore their relationships with the surrounding rocks are obscure at the present time.

Diorite and Gabbro. Several masses of diorite are exposed around Meddybemps Lake, Cathance Lake, and in Township 18; others are hypothesized on the basis of magnetic pattern in concealed areas such as Meddybemps Heath and an area on the Dennys River near Gilman Dam. The dioritic rocks have a medium grained hypidiomorphic granular texture and are composed of varying amounts of black and/or green amphibole, sodic plagioclase and occasionally minor amounts of quartz. Common accessories visible with a hand lens are pyrite, magnetite and biotite, but they do not occur in all of the specimens. Minor alteration by serpentinization has been observed in a roadcut outcrop at the base of Harmon Mountain in Northfield. Porphyritic varieties of the diorite with phenocrysts of amphibole up to ¾ inches long have been observed in many localities. They may occur either as clots up to 2 feet in diameter surrounded by equigranular diorite or else constituting the whole outcrop area.

On the shore of Meddybemps Lake at the southwest base of Staples Mt. a granite has intruded the diorite forming an angular intrusion breccia. Crustifications of epidote occur in association with the granitic veinlets, suggesting hydrothermal activity penecontemporaneous with the emplacement of the acid magma. In many places the granite and diorite form a composite mixture in which the hazy dioritic fragments appear to have undergone reaction with the granite. This material will subsequently be discussed under the heading of Granite-Diorite Breccia.

The diorite bodies have been delineated almost entirely by their distinctive magnetic pattern rather than by actual observation of their contacts with the other plutonic rocks. The anomalies connected with the better defined dioritic masses are usually steep sided and vary from 500 to 1000 gammas. Other exposures of diorite show only little or no anomalies and might possibly be shallowly underlain by granite. An alternate hypothesis is that the latter type of diorite occurrences average a smaller bulk magnetite content than the others.

Granites. Seven major varieties of granitic rocks have been recognized in the field and although their actual relationships to each other were not studied in detail, it is thought that they might all be members of the same intrusive complex.

The first type to be described is found in the northeastern part of the area and is subcontinuously exposed from Staples Cove to Magurrewock Mt. This rock is a medium grained, white, biotite granite. Its texture varies from allotriomorphic granular to hypidiomorphic. The latter variety frequently shows a lineation of tightly packed subhedral to ellipsoidal potash feldspar grains separated by thin septa of quartz and biotite. This same fabric is recognizable only with difficulty in the non-porphyritic varieties. Visible accessories found in many of the specimens are small amounts of sphene and magnetite.

A second type of granite is found from Cooper Mt. and the northern part of Cathance Lake to the southeast part of Meddybemps Lake. In contrast to the aforementioned white granite, this type is characterized by the presence of pale flesh to salmon colored potash feldspars. Small amounts of white sodic plagioclase can be identified in a few outcrops. The rock normally has a medium grained hypidiomorphic texture with a few larger grains of Carlsbad twinned potash feldspar, but occasionally finer grained slightly porphyritic varieties may be found. Biotite, occurring in variable quantities, is the only ferromagnesian mineral recognizable with a hand lens.

Around Spectacle Lakes and Vining Lake another granite containing flesh colored feldspar is exposed. This rock is a fine grained aggregate of flesh colored potash feldspar, sodic plagioclase, quartz, and biotite in that order of abundance. A peculiar texture caused by the presence of numerous phenocrysts of quartz with lesser amounts of idiomorphic feldspar serves as the main criterion for the recognition of this type. Vague clots of sodic feldspar grains in the sugary groundmass give the appearance to this rock of having been altered from its original composition or texture. Throughout the area of exposure many vuggy quartz veins and pegmatitic streaks are found but no ore mineralization was observed.

In a very small area 0.6 miles southeast of the Cooper Mt. fire tower a molybdenite bearing granite is found. According to Emmons[9] a small open pit mine with an underground drift and cross cut was operated in the early 1900's with only a very small production. The rock is a sugary textured, low biotite, white granite with an occasional subhedral phenocryst of potash feldspar or quartz. Small vugs as well as thin aplitic veins occur sparsely through-

[9] Emmons, W. H. (1910) op. cit., p. 42.

out this rock. Most of the molybdenite which can be found around the abandoned workings is rather small and occurs as widely separated disseminated grains or joint coatings in the granite. Larger specimens up to ¼ inch across may be found around some of the concentrating equipment but pieces up to one inch in diameter and ⅛ inch thick were shown to the writer by Mr. John Bacon of Wesley, Maine. In addition to the molybdenite, other accessories which occur in minor amounts are fluorescent zircon and scheelite.

A second type of granite high in quartz phenocrysts occurs in the southeast and northeast corners of Wesley and Northfield respectively. This biotitic granite is characteristically different from the Vining Lake variety in that it generally has a coarser texture and contains white to off-white feldspars instead of pink. In a few localities the phenocrysts are abundant enough so that the rock might properly be called a porphyry. Biotite altering to chlorite is the main dark mineral and occurs as discrete flakes or as fine disseminated inclusions within the groundmass. A small cupola of this granite is found in the fractured metasediments southeast of Seavey Lake. A 12 inch carbonate vein cutting through the granite contains small amounts of disseminated pyrite, chalcopyrite, sphalerite, along with traces of gold and silver. The cupola, exposed only at the top of a small rise, appears to be completely surrounded by metasediments and no other veins were observed in this locality. A silicified shear zone approximately 600 feet wide was found in this granite about 1.1 mile north of the Northfield-Wesley town line on Rt. 192. The material in this zone, consisting of druzy quartz coated with iron oxide and fragments of altered granite was reportedly mined for gold at one time. An assay of a grab sample failed to reveal more than a trace of gold. Float blocks of this material have been found up to a mile away to the northeast which, allowing for glacial transport, suggests that the zone extends for some distance in that direction.

The Round Lake Hills are composed of a granite consisting essentially of quartz and white feldspar. Dark minerals occur only in minor amounts with magnetite greatly predominating over hornblende. A rather sharp anomaly is associated with this rock at the easterly edge of Long Lake but no outcrops were found in the immediate vicinity. Because of variations in the magnetite content of the exposed rock, it might be possible that the anomaly represents a much higher concentration in that particular area. A similar leuco-granite was found about 2 miles south of Round Lake Hills but it is not known whether it is continuous with the larger mass to the north.

Granite-Diorite Breccia. In many places close to known diorite bodies, a mixture of dioritic fragments in a granitic matrix is exposed. The shape of the inclusions is usually subangular although some have sharp corners, and at the other extreme are merely dark irregular clots in the granite. Locally they contain ragged porphyroblasts of feldspar. Since all gradations of texture, shape and mineralogy are represented by these inclusions it is tentatively suggested that they might reflect diverse stages of reaction with the granite. The breccia has a rather discontinuous distribution, with the largest area occupying the extreme northeast corner of the flightstrip. The rock has a general marginal relationship to the diorites and is absent within the larger areas of granite. The breccia indicates that the granites are younger but does not show any direct relationship between the granitic types.

Since the white biotite granite, the pink biotite granite and the Red Beach granite (Robbinston) all are intrusive into the diorite, it indicates that all three are younger, and may be closely related in time. Similar relationships have been observed by Terzaghi[10] in the Columbia Falls quadrangle, but that writer has found evidence which indicates that the diorite and its differentiates around Jonesport are younger than the pink 2-feldspar granites around Jonesboro. It cannot be said at this time however which, if any of the aforementioned granites on the flight strip are equivalent to her Jonesboro granite. The field and age relationships of the diorite to the granite and the breccia lead the present writer to believe that the diorite represents the remnants of the roof of a magma chamber which has been broken up by its later granitic differentiates. The actual proportions of granite and breccia which exist and which might substantiate or refute this hypothesis are concealed beneath Meddybemps Heath and Meddybemps Lake.

Age of the Intrusives. No evidence other than their being younger than the Charlotte Group sediments was found to determine the age of these intrusive rocks. To the east in the Robbinston quadrangle, Bastin reports that the granites bear an intrusive relationship to the interbedded Silurian volcanics and sediments. Also, since the basal member of the Perry Formation (Devonian) contains considerable detritus from these granites in contrast to its absence in the Silurian rocks, Bastin believed that the granites were emplaced in late Silurian or early Devonian time. Terzaghi reports chilled relationships between her dioritic Jonesport series and the older pink Jonesboro granite, but no such relationships have been observed in the Meddybemps area.

Economic Aspects of the Area

Only a few indications of mineralization which did not look very promising were observed within the boundaries of the flight strip. The carbonate

[10] Terzaghi, op. cit., p. 12.

vein in the granite cupola near Seavey Lake carries values much too low to be called an ore. The silicified shear zone crossing Rt. 192 in Wesley lacks any mineralization other than a trace of gold. Although iron sulfides are found disseminated throughout much of the Dark Argillite equivalents, they are in quantities too small to be of economic interest. Iron sulfide veins occur in the southwest portion of the Calais quadrangle but do not appear to carry any other minerals. Sillimanite also occurring within this area represents perhaps less than 1% of the containing rock.

Such magnetite as is present in the exposed dioritic rocks is also economically insignificant with little chance of higher concentrations occurring at depth. The Cooper Molybdenite Mine shows very little ore in the walls of the workings at present time, considerably less than ½% of the exposed rock.

Conclusions

The airborne magnetometer survey which covered approximately 650 square miles in eastern Maine served as a valuable aid in outlining the geology of the region and indicated that a large percentage of it could be eliminated from a detailed program of ground prospecting. The most promising areas, i.e., areas of abnormally high magnetic intensities and highly variable magnetic pattern, exist within the metasedimentary belts in proximity to igneous intrusions. Due to the nature of the terrain it has not been determined whether these contact zones are mineralized. It appears necessary, therefore, to resort to other geophysical methods such as self potential, electromagnetic, and geochemical surveys to properly evaluate these anomalous conditions.

This magnetic survey has however resulted in arousing the interest of several mining companies who are at present actively investigating the region by means of the aforementioned methods but their results have not been made public.

PETROLOGY OF THE FARMINGTON, MAINE AREA

by

GARY BOONE

INTRODUCTION

The area studied is the northeast quadrant of the Farmington quadrangle, and lies east of the town of Farmington, in Franklin County, Maine (Fig. 1). This report is drawn mainly from a thesis submitted in partial fulfillment of the requirements for the M.A. degree in the Department of Geology at Brown University.

Keith's Geologic Map of Maine (1933)* indicates folded structures in Cambro-Ordovician and Silurian rocks in the Farmington area.

Pratt and Allen (1947) in their reconnaissance for limestone in Franklin County mapped several lithologic units and also indicated plunging folded structures.

The writer spent portions of two summers investigating the bedrock of the region east of Farmington. Lithology and structure were plotted on the Farmington quadrangle topographic map of the United States Geological Survey.

The main difficulty encountered in the area is the abundance of glacial drift deposits which mask the bedrock; this is especially true in a broad belt of stratified glacial deposits occupying the broad Sandy River Valley.

Physiography

The region of Farmington, Maine is located in the New England province of the Appalachian Highlands. Elevations in the area studied commonly lie between 500-600 feet above sea level. Maximum elevation in the area is Bannock Mountain, 1230 feet above sea level. Maximum relief of the area is 950 feet.

Glaciated hills rise above valleys filled with glacial deposits. In the vicinity of Clearwater Pond the topography has resulted from differential resistance to erosion: Mosher Hill, and the hills northeast of Clearwater Pond are composed mainly of quartzite and schist which are more resistant than the granodiorite underlying the topographic lowland occupied by Clearwater Pond.

* References are listed at the end of this report.

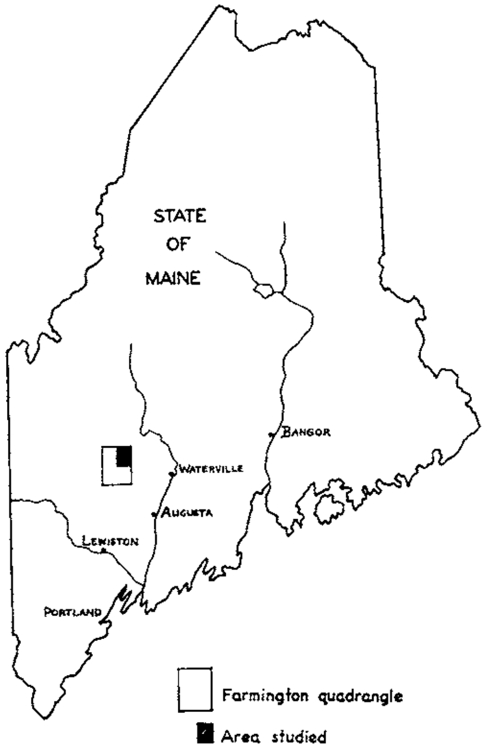


Figure 1. Location of area

The granodiorite is weathered along numerous fractures and joints and is quite friable. Cape Cod Hill owes its prominence to an intrusive body of alaskite which shows no effects of weathering. The streams of the area show no structural control.

Petrography of the Metamorphic Rocks

The region described in this paper is for the most part underlain by sedimentary rocks which have undergone low — to medium-grade regional metamorphism. They are mainly muscovite-biotite schist and quartzite. However, they may be subdivided into two groups, a northern and a southern group, on the basis of lithologic character (Map).

Northern Group of Rocks

The rocks of the northern group are composed of thin interbeds of quartzite, slate, quartz-muscovite-biotite schist, and graywacke. The thickness of these interbeds generally varies from an inch to several inches; at the most, the thickness is several feet. Gradations between these rock-types are common.

Except in quartzite and graywacke, foliation in the rocks is generally well developed. Both foliation and bedding in the rocks are highly inclined over the entire area. Some of the slate and fine-grained schists show linear structure.

Quartz veins are very common in this rock group; those of milky quartz predominate over veins of chlorite-bearing quartz.

The color of these rocks, on fresh surfaces, varies from light to dark gray. Visible minerals are usually quartz, muscovite, biotite, pyrite, and pyrrhotite. In many of the schists, the texture is uniformly fine-grained; in others, porphyroblasts of biotite are common, as well as lens-shaped masses of pyrite and pyrrhotite or the voids left by the weathering out of these sulphides. Cubes of pyrite are rare.

The iron oxides derived from the weathering of abundant sulphides produce a brownish coating over many of the outcrops.

Rocks of this northern group have been for the most part affected by regional metamorphism of low intensity. However, in the vicinity of Clearwater Pond, a small stock of granodiorite has intruded these regionally metamorphosed sediments and has masked the effects of regional metamorphism.

The bulk of this northern rock group is made up of fine-grained schist, designated generally as "phyllites" by Pratt and Allen (1947) and as "phyllites and argillites" by Keith (1933).

In thin section, all of the rocks show a fine-grained, crystalloblastic fabric. The common minerals are quartz, biotite, muscovite, pyrite, and pyrrhotite; chlorite is generally a subordinate constituent. The texture of graywacke varies widely and is composed of angular to sub-rounded grains of quartz, albite and oligoclase plus rock fragments. Sulphides are abundant. In all rocks of this group, rutile, zircon, ilmenite, and magnetite are the common accessory minerals.

The range in content of quartz in these metasediments varies from quartz-poor slate and pelitic schist to rocks which may have over 90 per cent quartz. However, in the schists, quartz commonly is between 35 and 45 per cent.

The texture of the schistose rocks in general ranges from fine-to medium-grained, and very commonly biotite occurs as porphyroblasts. In such porphyroblastic biotite schists, biotite is either subhedral with slightly ragged and irregular edges or shows tapered, elliptical or lensoid outline with smooth, sharply defined edges. In some rocks porphyroblastic ilmenite laths occur with no preferred orientation. In porphyroblastic biotite schist along Route 43, 1.9 miles north of Farmington, biotite has crystallized around and partially enclosed ilmenite. The biotite porphyroblasts characteristically are surrounded by sheafs of small muscovite and chlorite grains oriented normal to the surface of the porphyroblast. Most of the porphyroblasts are biotite, but some have completely altered to chlorite, still retaining the rim of muscovite and chlorite. The indication is strong that following the formation of biotite, solution and perhaps minor deformation continued with temperatures slightly below that required for the development of biotite and allowing crystallization of muscovite and chlorite in the " rims ", as well as allowing alteration of some of the biotite porphyroblasts to chlorite.

Much of the slate shows a lineation which is produced by fine, light bands of muscovite intersecting the foliation surface.

The quartzite varies from impure biotite-muscovite-chlorite-bearing quartzite to relatively pure quartzite in which actinolite and zoisite grains occur sporadically. Quartzite is also characterized by the freshness of the contained sulphide, which may be either pyrite or pyrrhotite. The sulphide is usually abundant in quartzite and invariably occurs as lens-shaped streaks scattered throughout the fine-grained, dark quartz matrix.

Although fine-to medium-grained graywacke commonly occurs interbedded with schist and quartzite throughout the rock group, coarse-grained graywacke is predominant enough over all other types in three localities to warrant mapping separately. The coarse graywacke along the southern slope of Mosher Pond Hill and its continuation on the west side of Mosher Hill road attains the greatest grain size. Cut and fill structures commonly interrupt the even, paralleled nature of the bedding. In this locality, the rock is characterized by angular and subrounded grains of quartz set against a dark, fine-grained matrix. In the field, relict graded bedding exists between alternations of graywacke and schist.

Light to dark green chlorite-bearing quartz veins occur sporadically throughout the rock group.

The degree of alteration in the rocks of this northern group varies considerably. In some, fine-grained aggregates of muscovite and chlorite, barely visible under high power objectives, may be the only evidence of alteration. In others, biotite shows all stages of alteration to chlorite.

The metamorphic rocks of this group are for the most part derivatives of sandstones, siltstones, clay-rich shales, and quartz-rich shales.

Contact Metamorphism

The low-grade regionally metamorphosed rocks which surround the Clearwater granodiorite were, in part, affected by thermal metamorphism during the intrusion of the stock. The effect of the contact metamorphism is varied both in the intensity and its areal distribution. The rocks in general are fine-grained quartz-muscovite and quartz-biotite schists, generally with porphyroblasts of biotite, garnet, or andalusite. In some specimens, all three minerals occur together as porphyroblasts. Some of the schists with high quartz content and low content of micaceous minerals show no effect of thermal metamorphism even at the contact. With increasing content of ferriferous and aluminous materials, first biotite, then garnet and andalusite have developed in close proximity to the contact. The greatest distance out-ward from a known contact where garnet and andalusite were found in rocks is 350 yards.

Although foliation is pronounced in some of the specimens, many others have a weak foliation or are massive. The porphyroblasts show no preferred orientation.

Along the southeast slope of Mosher Hill, the almandine-bearing schists show evidence of deformation after the crystallization of almandine. The almandine porphyroblasts show parallel strings of inclusions within them, and these, when referred to the rock foliation, show a rotation of almandine of about 50 degrees. Andalusite has altered to fine-grained muscovite.

The contact between the metasediments and the granodiorite is generally sharp, but on the southwest side of the cliffs rising from the peninsular lowland of Clearwater Pond, granodioritic materials have locally permeated the surrounding schist giving rise to a gradational contact slightly less than a foot wide. The granodioritic components of a specimen of the schist taken from this zone are even more apparent in this section.

Prominent ledges and cliffs several hundred feet northwest of the granodiorite and the cliffs rising from the peninsular lowland of Clearwater Pond show the most continuous, uninterrupted mass of andalusite schist to be found in the outcrops of contact metamorphic rocks. When viewed on a vertical face which is at right angles to the strike, the foliation shows broad flexures, but in general dips 72 degrees to the north. The rock also has a banded appearance: fine quartz-rich seams separated by thicker schistose layers. In the field and in the hand specimen, this takes on the appearance of sedimentary bedding, and the rock may have originated from shale with fine-grained sandy seams. Andalusite crystals make up 11% of the rock.

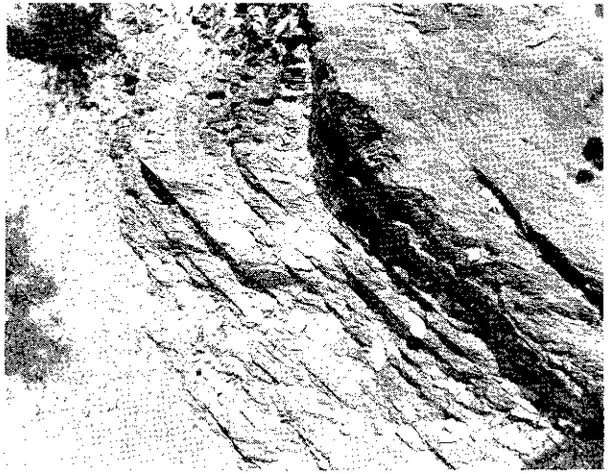
These show prominently on outcrop surfaces where they have been etched into relief by weathering. The crystals, 3 to 20 millimeters in length, are brownish-pink and are characteristically prismatic. The pink color of andalusite and one of its indices of refraction (na = 1.632) indicate about one per cent substitutional manganese in the Al_2SiO_5 structure.

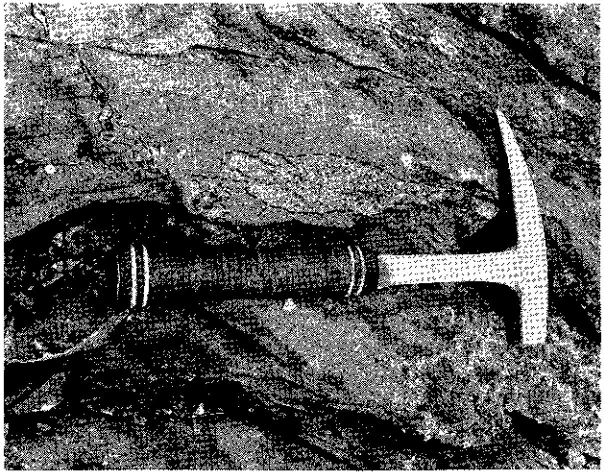
In this andalusite schist and others similar to it, the metamorphic grade is questionable. The assemblage of andalusite, biotite, almandine-pyrope garnet, and quartz indicates a degree of metamorphism intermediate between the cordierite-anthophyllite subfacies, and the staurolite-kyanite subfacies, both of the amphibolite facies. In rocks of excess potash (indicated by the presence of biotite), the typical pelitic assemblage of the cordierite-anthophyllite subfacies, usually considered as contact metamorphic, is muscovite, biotite, plagioclase, and quartz. In the staurolite-kyanite subfacies, usually considered a high phase of regional metamorphism, the assemblage biotite, almandine, sillimanite, plagioclase, and quartz is typical. The mineral assemblage, plus the relatively high amount of pyrope molecule in almandine garnet, indicates fairly high temperatures, with little stress. The assemblage may be an unstable one (Turner and Verhoogen, 1951, p. 456), and partial digestion of quartz and biotite by andalusite are evident in thin section by the irregular, rounded embayments in the biotite and quartz. These mineral inclusions show a ghost foliation extending through andalusite crystals.

North of Clearwater Pond, biotite schist and quartzite are interbedded but it was noticed in the field that the schist lacks good foliation, setting it apart from typical regionally metamorphosed schists. A thin section of this biotite schist shows a predominance of biotite adjacent to intersecting fractures filled with fine-grained muscovite, indicating solution and recrystallization along these fractures. However, biotite also occurs commonly as isolated porphyroblasts in the groundmass of quartz, fine-grained biotite, and muscovite.

The lack of a distinctive foliation and the diverse orientation of biotite show that directive pressure was not prevalent during the growth of biotite, although two preferred orientations of muscovite in the groundmass indicate that directive pressures must have been important previously. These relations, plus the larger grain-size of this rock in contrast to the regionally metamorphosed schists, may be sufficient to place the rock within the contact metamorphic aureole of the Clearwater granodiorite.

The highest grade of the rocks in the contact metamorphic aureole is attained by andalusite-almandine schists which are intermediate between the cordierite-anthophyllite subfacies and the staurolite-kyanite subfacies, both within the amphibolite facies.





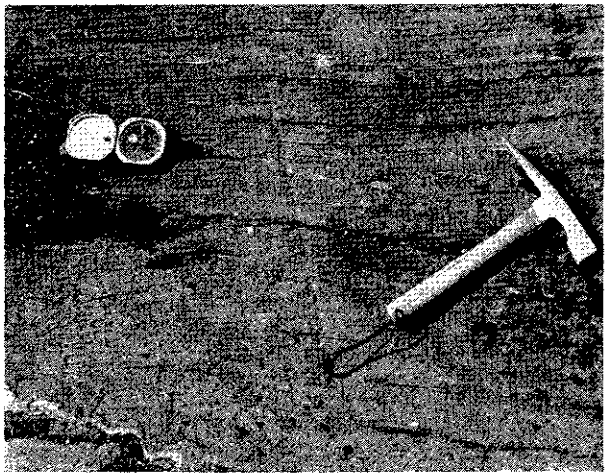


Fig. 1. Axial plane cleavage in slate. Route 43, 1.1 miles NE of Farmington.

Fig. 2 (upper right). Lenses of lime-silicate rock in quartz-biotite schist (near Farmington Falls, Maine).

Fig. 3 (at right). Relict bedding in andalusite schist. Outcrops on cliffs rising from peninsular lowland of Clearwater Pond.

Southern Group of Rocks

The rocks of this group are composed of interbedded quartzite and schists. The schists are medium-to-coarse-grained quartz-biotite schist with biotite porphyroblasts, almandine schist, lime-silicate schist, and staurolite-almandine schist. Interbeds are thick and gradational with one another. Less common are quartz-biotite gneiss and lime-silicate gneiss.

Except in quartzite, foliation is well developed. Lineation is generally lacking.

The rocks vary in color; quartzite is dark gray, quartz-biotite schist varies from gray to light gray, almandine schist is generally dark gray with reddish iron-oxide staining on foliation surfaces, lime-silicate schist and gneiss vary from light green to greenish-gray, and staurolite-almandine schist is gray to dark gray. Visible minerals are biotite, almandine, and staurolite, and actinolite and clinozoisite in staurolite-almandine schist and lime-silicate schist and gneiss, respectively.

Except for iron-oxide staining on foliation surfaces in quartz-biotite and almandine schists, the rocks show little weathering.

Rocks of this southern group have been for the most part affected by regional metamorphism of low to medium intensity, as represented by rocks in the greenschist and amphibolite facies.

In general, all of the rocks show a medium-grained crystalloblastic fabric, the common minerals being quartz, biotite, muscovite, chlorite, almandine, and staurolite; in the lime-silicate rocks, actinolite, calcite and clinozoisite are common constituents. Rutile and magnetite are common accessories in the pelitic schists, whereas sphene is an abundant accessory in the lime-silicate rocks.

The texture of the pelitic schists is commonly porphyroblastic with large crystals of biotite randomly oriented in a light colored quartz-muscovite groundmass. In contrast to the schists of the northern group of rocks, magnetite and rutile are the accessories, instead of pyrite and pyrrhotite.

Less commonly, biotite porphyroblasts show irregular, subhedral outline, as displayed in a quartz-biotite schist from the Weeks Mills - New Sharon road. Biotite is poikilitic and encloses and embays grains of quartz. The groundmass is made up of fine-grained quartz and biotite; in this rock, muscovite is a rare constituent of the groundmass. Accessory minerals are small grains of zircon and large grains of magnetite which poikilitically enclose quartz.

Small streaks, " veins ", and lenses of lime-silicate rock are an interesting, abundant, and characteristic feature of this rock group and occur in quartz-biotite schist. An outcrop of quartz-biotite schist with irregular lenses of lime-silicate rock, from the West Farmington road, 2.35 miles from Farmington Falls, shows typical relationships (Fig. 2). Irregular seams and pods of the lime-silicate rock cut through the schist in dike - or vein-like fashion without regard to foliation. Megascopically, their texture and fabric are suggestive of a dioritic igneous rock, and similar lime-silicate rocks have been thus interpreted (Keith, 1913, pages 684, 685). The contact between the more non-foliated lime-silicate rock and the biotite schist is rarely sharp, and commonly imperceptible gradations exist between the two types, over distances ranging from an inch to several inches.

In this lime-silicate rock actinolite occurs as porphyroblasts; one of the grains, or two or three together, produce the green " lenses " seen in a hand specimen. The porphyroblasts are subhedral and irregular in outline and, for the most part, poikilitically surround and embay grains of calcite, quartz, clinozoisite, and zoisite, which are the principal minerals of the groundmass. The groundmass minerals are about equal in size and display a crystalloblastic fabric. They are commonly surrounded by interstitial material composed of a fine mixture of chlorite and muscovite.

It is believed that the quartz-biotite schist was originally impure sandstone or shale, with irregular lenses and seams of limestone, and that the limy material achieved greater mobility during deformation: occupying fractures to form veins, and thinning out to form lenses and streaks.

Lime-silicate rock also occurs as regular interbeds — probably relicts of thin limestone beds — within the pelitic schist and gneiss and displays a different appearance and texture than the lime-silicate seams and lenses described above. An example is lime-silicate schist from near the West Farmington road, 2.4 miles from Farmington Falls. The rock is fine- to medium-grained, and may be termed gneissic or banded schist; the banding is evident from alternate layers and streaks of biotite-rich, and actinolite-rich bands. The characteristic mineral assemblage is quartz, biotite, actinolite, sphene, chlorite, and bytownite.

The assemblage actinolite-biotite-bytownite indicates a metamorphic grade equal to the staurolite-kyanite subfacies of the amphibolite facies. The composition implies metamorphism of an impure shaley limestone.

On the northeast side of Route 2, 0.8 mile north of Farmington Falls, a composite granodioritic sill has intruded lime-silicate schist and gneiss, locally giving rise to a more varied mineral assemblage and a higher grade of metamorphism than in the immediately surrounding regionally metamorphosed rocks.

Thin beds of staurolite-almandine schist occur widely separated throughout the southern group of rocks. The staurolite-almandine schist from near the Bragdon Brook road contains abundant, conspicuously large staurolite porphyroblasts 10-20 millimeters in length. The almandine porphyroblasts, however, are commonly 2-3 millimeters in diameter. Twinned staurolite is present but not common. Other minerals present are quartz, muscovite, biotite, ilmenite, tourmaline, and chlorite. Zircon is an accessory, and clouds of fine-grained opaque material dispersed throughout the groundmass and porphyroblasts may be magnetite.

Staurolite invariably shows zonal structure. In some cases a ghost foliation extending through the crystals is revealed by the arrangement of poikilitically enclosed fine-grained quartz.

For the most part, staurolite in the schists previously described is fresh, showing only partial alteration to chlorite along fractures and incomplete rims of chlorite on crystal surfaces.

In virtually all the lime-silicate rocks which contain actinolite, alteration of actinolite to chlorite in varying degrees is evident. The lime-silicate schists from the West Farmington road and from Weeks Mills generally show less alteration of actinolite to chlorite, than does biotite.

Petrography of the Igneous Rocks

The igneous rocks of the region range in composition from alaskite to granodiorite, and are found as sills, stocks, and dikes. Foliation is generally lacking.

It is believed, on the basis of fabric, that the composite granodioritic sill north of Farmington Falls and the stock of alaskite underlying Cape Cod Hill were the first to intrude the area. Bent, fractured, and crushed mineral grains are seen in thin section. Then followed the Clearwater granodiorite stock, showing no deformation in thin section, and the associated granitic sills on the small hill northeast of Clearwater Pond and granodiorite on the cliffs rising from the peninsular lowland of Clearwater Pond. The dike of granodiorite porphyry on Bannock Mountain may have been emplaced synchronously with the igneous activity in the vicinity of Clearwater Pond, as is suggested by its similarity in composition to the coarse-grained granodiorite.

Low temperature alteration is evident in all of the igneous rocks. This is shown by chloritization of amphibole and biotite, the production of muscovite and calcite in feldspar, and the formation of epidote which is considered by some workers (Johannsen, 1932, vol. 2, p. 181) to be a deuteric mineral in igneous rocks.

Cape Cod Hill, in the extreme east central part of the quadrangle, owes its topographic prominence to a small, stock-like body of alaskite, which outcrops at many places on and near the summit of the hill. The rock is quite fresh, and sheeting is well developed. In many places near the summit, former quarrying activities are evident. Dikes of aplite and pegmatite are common, in places offset by small scale strike-slip faulting.

The massive rock is light gray in color and is medium- to coarse-grained. The feldspar of the rock is whitish in appearance. Both muscovite and biotite are present, and the muscovite commonly occurs as very large grains, in contrast to biotite.

In the vicinity of Clearwater Pond, granodiorite is found in three localities. One of these is the southeast slope of Mosher Hill; another is on the east shore of the pond; the third locality is the cliff face rising from the peninsular lowland of Clearwater Pond. The granodiorite in each locality is thoroughly intersected by joints and fractures along which weathering has taken place. Small aplite and pegmatite dikes cut the intrusive at the exposures on the east shore of the pond.

The granodiorite of Mosher Hill contains biotite but no muscovite. That on the east shore contains both biotite and muscovite, while the granodiorite on the cliffs rising from the peninsular lowland of Clearwater Pond contains muscovite as the only mica. One might infer from these differences in mica content and other mineralogical disparities that the stock is a composite of three intrusions, but in the absence of structural evidence for this, the hypothesis of a single intrusion is favored. The rock in each locality is quite friable and coarse textured. The granodiorites are whitish or light gray on fresh surfaces, although iron oxide staining is always abundant throughout them. No structure is evident. The modal compositions of the rocks reveal them to be sodaclase granodiorites.

A granodiorite porphyry dike can be traced from near the summit of Bannock Mountain down its western side. The dike is about 8 feet wide and its contacts show that it was intruded along a prominent direction of vertical jointing. Near the contacts the rock is dark gray and fine-grained. Abundant white phenocrysts of plagioclase are visible and are about two millimeters in size. The central part of the dike is lighter in color. The entire dike weathers to a light gray and in the weathered portions phenocrysts of chlorite show the outline of amphibole. No foliation or linear structure is evident in the dike.

Metamorphism of the Sedimentary Rocks

The Facies Concept

Because the rocks of the Farmington area are mainly pelitic, the discussion of critical minerals which indicate grade of metamorphism is warranted and useful if applied only to this region. However, classification by metamorphic facies is more frequently used since it allows pelitic rocks and calcareous rocks of the area to be compared in the same terms of metamorphic grade. Where lime-silicate rocks are involved, actinolite, zoisite, diopside, and the pair calcite-quartz are useful for comparative purposes.

Phases of Metamorphism

Progressive regional metamorphism, contact metamorphism and retrogressive metamorphism have taken place in the area. In general, they follow that order. Evidence suggests that the regional, dynamo-thermal stage of metamorphism came first and that contact metamorphism accompanying the intrusion of the Clearwater granodiorite occurred as a late phase of regional metamorphism. Several observations support this:

1. Except for the area immediately surrounding the Clearwater granodiorite, the same textures and mineral assemblages occur in ubiquitous fashion with only minor variations. Igneous intrusions are absent.

2. Structurally, there is a monotonous regularity in the strike and dip of the metasediments. This is due to parallel, isoclinal folding of pelitic, calcareous, and arenaceous rocks on a regional scale.

3. The minerals which have developed during contact metamorphism in the rocks surrounding the Clearwater granodiorite partially mask the texture and in some exposures the structure so generally seen in the rocks beyond the contact zone. Almandine garnet and andalusite are minerals peculiar to the rocks surrounding the granodiorite and are not found within the regionally metamorphosed northern group of rocks. Schist with spotted structure produced by clusters of biotite and chlorite is also restricted to the vicinity of the Clearwater granodiorite. It is believed that in this locality andalusite has originated by contact metamorphism since it occurs in rocks of a higher metamorphic grade only in places surrounding the granodiorite.

4. It is probable that granitic and granodioritic intrusive activity in this region is a late stage phenomenon in the folding and regional metamorphism of geosynclinal sediments. The intrusives occur after and synchronously with the later stages of folding activity. As evidence for this supposition, the stock of alaskite on Cape Cod Hill and the composite granodioritic sill north

of Farmington Falls on Route 2 both show an allotriomorphic-granular texture with evidence of shearing shown by parallel trains of shredded muscovite and fine-grained quartz, bent cleavage traces in muscovite, and bent twin lamellae in plagioclase feldspar. The Clearwater granodiorite on the other hand shows by its sharp contacts cutting across the foliation and its hypidiomorphic-granular texture unaltered by cataclastic deformation, that it was intruded after folding in the area had ceased. The thermal metamorphism accompanying this intrusion is, therefore, later than the folding.

The evidence for retrograde metamorphism is found in numerous examples of mineralogical reversal — high-temperature minerals altering to lower temperature forms. In the rocks of the northern group numerous examples were found where biotite has altered to chlorite. In the rocks of the southern group both biotite and actinolite show alteration to chlorite. Staurolite shows alteration in rims of chlorite about its edges; in one locality it has undergone complete alteration to chlorite and muscovite. In the contact metamorphic rocks surrounding the Clearwater granodiorite both biotite and garnet show alteration to chlorite. Andalusite has altered completely to masses of fine-grained muscovite in some localities.

The place of retrogressive metamorphism in the sequence of metamorphic events in the area is generally the final expression of metamorphic change in these rocks. There is no mineralogical or textural evidence that the minerals produced by retrogressive metamorphism have been in any way altered by further deformation or that there has been further growth of new minerals.

During regional and contact metamorphism of the area it appears that in terms of bulk composition, isochemical relations were prevalent. Rocks in which modal composition was determined revealed bulk compositions consistent with those probable in the original sediments.

Paragenesis of Pyrite and Pyrrhotite

The rocks of the northern group of metasediments invariably contain abundant pyrite and pyrrhotite. The two possibilities for paragenesis of iron sulphide in these metasediments are: (1) that original sulphide was formed by biogenic activity during deposition, or (2) that pyrite and pyrrhotite have been hydrothermally introduced. The occurrence of iron sulphide in these rocks does not seem to be restricted in any way by lithologic variations in the metamorphic rocks, inasmuch as it occurs abundantly in quartzite, slate, schist, and graywacke. Krumbein and Sloss (1953, pp. 366-368) note the occurrence of pyrite in eugeosynclinal sediments. Pyrite in this area is rarely found well crystallized, and it characteristically occurs as fine streaks and lenses scattered throughout the rocks and as isolated minute grains in the groundmass. Rarely, distorted cubes were found. It does not occur in the numerous quartz veins throughout the area or in igneous rocks. In thin section study no evidence was found to support hydrothermal introduction of iron sulphides and it is believed that the pyrite and pyrrhotite originated during or immediately following deposition by biogenic processes. The fact that pyrite is grouped into large masses, but does not show crystal outline, leads to the belief that shearing stress may have deformed the original crystal outline. The limited occurrence of distorted cubes lends support to the argument. Pyrrhotite offers a lesser problem since in general, its habit is not to crystallize readily.

Rock Fabrics

Relict Sedimentary Structures

Bedded structure commonly persists in the metamorphic rocks of the northern group, as has been mentioned in the description of the group. Relict bedding is especially marked in the zones of predominant graywacke, where numerous repetitions of graded bedding are seen in clear detail. The sequence is graywacke, quartzite, schist, and slate.

Thin, alternating color-bands in fine-grained schist north of Withee Corner may represent varved clays. Irregular wavy-bedded structure (cf. p. 126, Pettijohn, 1949) is found in quartz-biotite schist north of Clearwater Pond where thin, curved bands are truncated on top and bottom by others of the same nature.

The banded appearance of andalusite schist on the cliffs rising from the peninsular lowland of Clearwater Pond is produced by alternate andalusite-rich and quartz-rich bands. There is no evidence suggesting how much of the banded appearance is due to original sedimentary bedding and how much to metamorphic differentiation of rock components into layers. The banding is thin, very sharply defined and commonly lenses out. Thin section study lends no support to either interpretation, but the appearance in the field suggests relict sedimentary bedding (figure 3).

Metamorphic Structures

Indications of metamorphic conditions are commonly given by microstructural relations. In this sense, the roles assumed by the relation of porphyroblasts (biotite, garnet, andalusite, and staurolite) to the groundmass are particularly useful in rock fabric interpretation.

No matter what is the form of biotite porphyroblasts in quartz-muscovite-biotite schist of regional metamorphic origin, the groundmass shows a well developed foliation by the parallel arrangement of muscovite. This arrangement indicates the presence of stress during metamorphism. However, it is believed that biotite and staurolite porphyroblasts are useful in determining the concurrence of, or lack of concurrence between periods of stress and the period of rising and peak temperatures during which time these porphyroblasts must have developed.

Relict Metamorphic Structures

The most consistent relict metamorphic structure is the parallel arrangement of groundmass minerals in the contact metamorphic rocks. It is believed that this structure is relict from previous regional metamorphism since not only andalusite and almandine truncate and in places mask the foliation, but biotite has profusely grown in random orientation, masking parallel structure and developing a decussate pattern. Divergence of foliation around these minerals is completely lacking. In general, rocks produced by purely thermal metamorphism are characterized by their lack of foliation. In some of the andalusite schist, " ghost " or relict foliation is produced by parallel alignment of quartz grains trending through andalusite. In other cases, the only evidence that porphyroblasts were once andalusite is a chiastolite structure persisting in sharply defined zones of fine-grained muscovite.

As mentioned previously, fabric relations in the contact metamorphic rocks surrounding the Clearwater granodiorite show, by the rotation of linear structures in almandine, that some deformation occurred after its growth, and that this deformation may be responsible for the alteration of andalusite to fine-grained masses of muscovite with relict crystal outline of andalusite.

Causes of Metamorphism

The fact is obvious that folding and regional metamorphism were closely associated in time. Igneous activity may have been initiated at great depths during the folding. Heat from underlying igneous activity plus frictional heat generated by shearing stress may have supplied the high temperatures requisite for progressive regional metamorphism although deep burial into regions of higher temperature may have helped supply or helped to maintain high temperature for metamorphism. The hypothesis is entertained that the small granitic stocks, sills, and pegmatites of the area are a later, higher-level manifestation of this igneous activity and supplied the heat for contact metamorphism after regional metamorphism, or most of it, had been accomplished. It seems probable that activation of low-temperature fluids throughout the regionally metamorphosed rocks was the most distant expression of rise in temperature surrounding the late stage igneous intrusions. Contact metamorphism in the rocks immediately surrounding the Clearwater granodiorite may have taken place simultaneously with low-temperature retrogressive changes in the regionally metamorphosed rocks. The contact metamorphic rocks themselves may have been the last to undergo retrogressive metamorphism as the intrusive body of granodiorite cooled and solutions continued to migrate throughout the contact metamorphic rocks. Retrogressive metamorphism in the contact metamorphic rocks may have been simultaneous with low temperature alteration within the granodiorite.

Structure

The foliation and relict bedding of the rocks in the area almost everywhere dip steeply to the northwest; in a few places the dip is southeast. The general strike of the metasediments is N.35°E., but varies as much as 30 degrees to the north or east. Graded bedding in several localities indicates younger rocks to the southeast. With the general agreement of foliation and relict bedding in both strike and dip, it is believed that the rocks have been folded isoclinally with the folds overturned slightly to the southeast. Key beds are lacking upon which to base more exact structural interpretation. Where folded relict bedding in fine-grained schist and slate has been etched out by erosion, axial-plane foliation is observed.

Isoclinal folding has taken place with repetition of beds, although no reversals in graded bedding mentioned above, were found. In the absence of conclusive evidence, the southern group of rocks is indicated tentatively as being younger than the northern group, on the basis of graded bedding in graywacke localities, which indicate a younger succession toward the southeast.

Graded bedding as seen in graywacke localities shows that the beds have been overturned to the southeast. Foliation (that is, schistosity and slaty cleavage) in the finer-grained metasediments are in general parallel to the bedding.

However, in areas where finer-grained schist and slate predominate over quartzite and graywacke, foliation does not parallel lithologic contacts (Fig. 4). Where these relations of interbedding hold true and relict bedding is deformed by small scale folds, the strike of the foliation deviates less from north to east than does the strike of the beds, and bedding dips more steeply than foliation. This relationship was found in three widely separated localities and indicates the rocks are in a northwest limb of a slightly overturned, southward plunging syncline, or southeast limb of an anticline.

Correlation and Age of Rocks

The age of the metamorphosed sedimentary rocks is believed to be early Paleozoic, although paleontologic evidence is lacking. In general, the metasediments conform to the regional structure of central and western Maine, northern New Hampshire, and New Brunswick. These structures resulted from the Acadian orogeny of middle Devonian age (Schuchert, 1930 and Dunbar, 1949, pp. 203-206) and the rocks described in this paper are therefore believed to be pre-middle Devonian. Kay (1951, p. 54) states that plutonic intrusions accompanied the Schickshockian (Acadian) orogeny, intruding pre-middle Devonian sediments. The occurrence of granodioritic intrusives in the Farmington area agrees with the sequence of events reviewed by Kay. Keith (1933) considers the rocks of the area to be Cambro-Ordovician and Silurian, but no evidence to confirm this was found in the area studied.

Correlation with rocks of known age and similar lithology in the Waterville area (Perkins and Smith, 1925) is at present not possible. C. W. Wolfe (personal communication) states that fine-grained, sulphide-bearing schist and quartzite in the vicinity of Phillips, Maine, similar to the northern group of rocks of this paper, are of lower Silurian age.

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SCHEELITE OCCURRENCES IN MAINE

by

JOSEPH M. TREFETHEN, HENRY ALLEN, and WILLIAM T. FORSYTH

Scheelite in the calcium tungstate, $CaWO_4$; when pure it contains 80.6% WO_3. Often associated is *powellite,* $(Ca,Mo)WO_4$. These minerals, therefore are sources of tungsten. This metal is used in manufacture of light filaments; high speed tool steels which retain a cutting edge up to a red heat and are hard and abrasion resistant; tungsten carbide a substance inferior only to diamond in hardness. There are various other lesser uses, also, and consequently tungsten is in keen demand, the more so because the United States imports a large portion of its needs from abroad, especially from the far east.

Several types of deposits can be recognized, but the one most important in Maine, so far as seen up to the present, is in the contact zone of granitic intrusives invading calcareous sediments. In these zones of favorable lithology a skarn, or contact metamorphic rock generally with grossularite (lime garnet), diopside, quartz, and epidote, is the host for the scheelite. It would appear that the igneous rock magma was the source of the tungsten, the calcium being derived from the limey sediment. With the ultra violet lamp scheelite glows a pale but brilliant blue; the powellite glows yellow. Consequently most of the prospecting of these lime contact zones is done after dark with the light. The favorable exposures are found and studied in daylight, and subsequently checked after dark. Most of the localities where scheelite has been found here are in the western part of the state. This is probably because of the abundance of pegmatite that has been a carrier of the tungsten into the limey host rocks. Checks in the limestone belts that have been studied in the Rockland-Thomaston region have not revealed scheelite to date.

Swift River Valley

Traces of scheelite were reported in the Swift River Valley by Henry Condon, of the U.S. Geological Survey, in 1947. Subsequently, Forsyth and Trefethen, in company with Stanley I. Perham and one of his associates visited a location of interest to Perham, and subsequently, Forsyth and Millett checked many exposures with the light.

Traces of scheelite have been found associated with small zoned lenticular bodies of quartz, diopside, garnet, and iron sulfide in the bed of the Swift River near the town line separating Houghton from TWPD. These lenses or pods consistently bear a zonal structure but the sequence of zoning may vary. They are more commonly found parallel to the foliation of a staurolite — garnet schist in which the twinned porphyroblasts of staurolite are marginally or completely altered to chlorite. The pods vary in length from six inches to eight feet and are much more massive than the surrounding schist. All observed contacts with the schist are gradational and reflect the possibility that they might have been produced by metamorphic differentiation.

The most common type of zoning consists of a thin rim of granular quartz grading inwardly to a zone of diopside or hornblende clusters and quartz with small amounts of pink garnet. This in turn grades into a core where quartz is abundant and intimately mixed with the finer diopside or hornblende and much coarser pink garnet. In smaller pods from one to three inches thick, this order may be quite irregular and occasionally inverted.

A half inch grain of scheelite was found on the Swift River in the core of one of these pods about ⅛ mile above its confluence with Mott Stream. About ½ mile further upstream a larger amount of scheelite is present in a similar type of rock, but occurs as fine disseminated grains ranging from pinpoint size to ⅜ inch across. This mineral also occurs in this outcrop as a ⅛ inch vein cross cutting the pod at a high angle. An assay made on material from this locality revealed a tungsten content of 0.26% which is quite a bit below the commercial grade of ore. The sparse distribution of these pods coupled with their low tungsten content does not indicate to this writer that they have much chance of being worked commercially.

Another occurrence of scheelite in the same region was pointed out to the writer by Mr. Norman Young of Byron, on whose property the mineral was found. The site is approximately ½ mile up the second south flowing tributary above the mouth of the East Branch of the Swift River (see Rumford Quadrangle, USGS, 1946). Just below a small bridge over this stream many rusty massive quartz veins averaging one foot in width are found closely paralleling the foliation of a fine grained muscovite-garnet schist. The scheelite was originally found by local prospectors who traced float blocks up stream to this point. Scheelite was not found *in situ* at the bridge where Forsyth was shown approximately a bushel of scheelite bearing quartz fragments. Although all of the quartz veins examined proved to be barren, their similarity to the scheelite bearing loose and collected material is striking; it appears that the quartz scheelite vein material is probably of local origin.

Two other occurrences of tungsten were also found in this general region but again only in trace amounts. The first was on Mountain Brook, a secondary tributary of the Swift River in a well banded lime silicate gneiss.

Only randomly scattered pinpoints of the scheelite were observed in the almost continuously exposed ledge constituting the bed of the brook. Also in similar concentration, the scheelite was found on the westerly side of Partridge Peak north of Roxbury Notch. The host rock was a lime silicate quartzite with very poorly developed banding.

In conclusion, it can be said that all the observed scheelite occurrences in this region are quite small, randomly scattered and of little economic interest. All but one is in rock containing larger than normal amounts of CaO and all of those are within ¾ mile of known granite exposures. Apparently the combination is one favorable to the deposition of tungsten minerals but not enough was available to produce a workable deposit.

Cornish

Dr. L. W. Carpenter, M.D., of Limerick, Maine, pointed out and accompanied the field party to a scheelite locality on the Berry Farm in Cornish, Maine. The property is on the westerly side of Route 5 approximately two miles north of the Limerick-Cornish town line.

Lime silicate gneiss is found abundantly in the area and has a banded structure due to alternation of quartz rich and diopside rich layers. In some places the layering is absent with the rock consisting of a massive mixture of the same minerals. Locally crustified and vuggy skarn or tactite zones are present containing such lime rich minerals as grossularite, idocrase, scapolite, pectolite, calcite, and scheelite in addition to the diopside and quartz. One of these zones is exposed in the road cut and has been worked extensively by mineral collectors because of the excellent crystal aggregates found there.

Quartz-biotite-feldspar schist and gneiss are found intermixed with the lime silicate rocks. Contacts may be either sharp or gradational. The biotitic rocks are much more fissile than the lime silicate rocks and carry veins of quartz and granitic pegmatite parallel to the schistosity.

Granite occurs in numerous places throughout the area in various mineralogical and textural phases such as aplite, medium grained biotite granite, medium grained muscovite granite, and medium grained boron pegmatite. Several dikes of granite and pegmatite have been observed cutting both the lime silicate rock and the biotite schist. The survey was not carried out over a sufficient area to determine whether the concentration of granite and pegmatoid granite outcrops near the farm buildings were veins or part of a larger intrusion.

Basic dikes which are fairly numerous cut through all the aforementioned rocks. These dikes have a fairly consistent northeasterly trend and are nearly vertical. Fragments of basalt may be found coating surfaces of other rocks in planes approximating the normal direction of solid dikes. The largest of these dikes, about fifteen feet thick, has a diabasic texture with fine grained chilled margins such as were observed as attached fragments on other outcrops. In the road cut, a basic dike was found cutting through a granite dike which in turn had intruded the tactite.

The sequence of geologic events seems to be as follows: (1) Regional metamorphism of shaly and calcareous sediments, (2) Intrusion of granites and pegmatites with accompanying pneumatolytic activity creating the tactite, (3) Intrusion of the basic dikes.

Masses of scheelite up to two inches across were located in the strongly deformed tactite as indicated by S-1 on the accompanying map. Twelve feet west of the road a test pit has been dug in which smaller amounts of scheelite have been encountered. Other test pits within a radius of 25 feet failed to produce any more scheelite. None of this mineral was found in the deep road cut by the party. The only additional locality where scheelite was found is indicated by S-2 (map). It was detected as a few pinpoint grains but other samples from the same outcrop were barren. Dr. Carpenter reports that before Route 5 was hard surfaced it was possible to find some scheelite in that part of the outcrop underlying the road.

Pease Mountain Scheelite Occurrence

During the summer of 1954 Allen found scheelite occurring in skarn rock of a lime silicate gneiss formation at the contact with quartz syenite pegmatite at an elevation of about 980 feet on the southwest slope of Pease Mountain in Cornish. This occurrence is directly across the Little River valley from the Berry's Ledge scheelite prospect on Day Hill.

The skarn rock appears to be a thin dip slope erosional remnant being only 3 to 5 feet thick at the most resting on top of a quartzose gneiss. The skarn rock can be followed for about 75 feet along the strike (S 55° E) parallel to the mountain side and for about 30 feet down the dip. To the southeast the lime silicate rock is cut off by a granite or quartz syenite. Quartz syenite pegmatite was also observed to be in contact with the skarn rock. Another small showing of lime silicate gneiss was observed a short distance to the west but overburden prevented a detailed study.

Present in the skarn rock are typical skarn minerals such as diopside, grossularite garnet (both massive and euhedral forms), and crystals of idocrase. Scheelite occurs as disseminated crystals a fraction of an inch in diameter. Most specimens collected showed at least a trace of scheelite.

Since the erosional remnant appears to be a pretty small mass it hardly qualifies as a prospect. However, additional prospecting along the slopes of Pease Mountain may reveal the main igneous-lime silicate rock contact. The valley of Little River between Day Hill and Pease Mountain appears to be underlain by the lime silicate formation.

Sanford

Minor amounts of scheelite and molybdenite are associated with the well known Sanford vesuvianite deposit. The small pit from which many excellent crystal specimens have been extracted occurs about 250 feet northeast of School Street in a field 1.2 miles south of Central Square in Sanford, Maine. At the present time the pit is partially filled with rubble from the surrounding cleared fields.

A massive aggregate of vesuvianite crystals constitutes most of the walls of the pit but this material grades out into a banded lime silicate gneiss on the northwest wall before coming into contact with a medium grained biotite granite within thirty feet. Lime silicate gneiss also occurs to the southwest and seems to limit the vesuvianite in that direction. Granite is found to the southeast but no bedrock was located in a northeasterly direction from the pit. Apparently the vesuvianite deposit is sandwiched in between granites on the north and south and extends in a northeast-southwest direction for an indeterminate distance.

Dump material around the pit contains occasional grains of scheelite up to ¾ inch in length. Smaller grains of molybdenite coated with molybdite or powellite are frequently associated with the vesuvianite also. Other minerals identified megascopically in the area are diopside, zircon, quartz, and calcite. No scheelite was actually found in place in the limited exposures available.

Newfield

Visits were made to a new scheelite prospect on Piper Hill about two miles northwest of Newfield village in the town of Newfield. The property is owned and has been prospected by Mr. Hans Bergendahl of Kezar Falls, Maine.

Several good exposures of quartz-poor pegmatite, which has intruded and engulfed blocks of lime silicate gneiss show near the top of the hill on the northern side. Several prospect holes have been blasted out to a depth of from two to four feet in contact areas between pegmatite and the lime silicate blocks. From the top of the hill toward the east and south, exposures indicate the pegmatite to be the underlying rock of the hill in those directions.

Ultra-violet lamp examinations show the scheelite to be pretty much confined to lime silicate blocks. The best show in the prospect hole area was noted in prospect pits near the top of the hill. Here scheelite occurs as " hot spots ", a fraction of an inch in diameter, concentrated as a rule in certain favorable layers.

Skarn minerals have not developed in great abundance in the lime silicate rock as a result of the intrusion of the pegmatite. Grossularite, a calcium garnet, appears to be the most common skarn mineral but not as abundant as at Berry's Ledge in Cornish.

Examination of available exposures indicates a much higher percentage of pegmatite relative to the volume of lime silicate rock. Since the scheelite occurs in small (a few feet across) roof pendants or engulfed blocks of lime silicate gneiss it would appear that the depth of mineralization was rather shallow near the top of the mountain.

More productive prospecting down the northern slope of Piper Hill seems likely since the main lime silicate gneiss - pegmatite contact appears to be present there. Considerable overburden makes prospecting difficult.

Recently, Mr. Bergendahl has located a large angular boulder, probably not far out of place, on the north slope of Piper Hill. An excellent showing of scheelite as small and large disseminated " hot spots " are present throughout the boulder.

During the examination of specimens from the dump piles of an old abandoned " lead-silver " mine on the Ray Davis farm approximately 0.1 mile southwest of Shady Nook in Newfield, Maine, scheelite was noted. According to Mr. Davis, the mine was last worked for lead and silver about 1906. The mine shaft is reported to be 100 feet deep but is filled with debris to within 15 feet of the surface. At the 35 foot level a horizontal drift is supposed to extend out toward the southeast.

Walls of the upper part of the mine shaft as well as specimens found near the mouth of the shaft (probably came from lower levels) were examined under an ultra-violet lamp. On the northern and southern walls of the mine shaft at the contact between pegmatite and lime silicate gneiss, scheelite was found to be disseminated as " hot spots " in quartz-calcite rich bands in the lime silicate gneiss. The mineralized zone below the pegmatite contact measures at least two feet wide down to the top of the debris which prevented observation of the walls to deeper depths. The contact between the overlying pegmatite and the lime silicate gneiss is nearly horizontal but undulating.

The calcite content of the lime silicate gneiss appears to be 5 to 10 per cent on the average. Pyrite and arsenopyrite are abundant and silicification seems to have taken place to a considerable degree.

It is believed that tungsten mineralization has taken place to greater depths since rock fragments laying near the shaft on the top of dump piles probably were brought from the last worked level of the mine.

Farmington

Two scheelite occurrences in the Farmington area were noted by Mr. Gary Boone in the course of his mapping in this region (see elsewhere in this report). The first of these is approximately two miles north of Farmington Falls on the West Farmington - Farmington Falls road, and the second one mile north of Farmington on Route Two. At the first locality, the scheelite occurs as minute grains disseminated sparsely in the lime silicate rock. At the second locality, the scheelite is associated with one inch veins of coarser grained calcite and zoisite.

BENEFICIATION TESTS ON THE WARREN SILLIMANITE GNEISS[1]

WILLIAM T. FORSYTH

INTRODUCTION

A sample of sillimanite gneiss from the property of Hollis Starrett in Warren, Maine was taken by the Maine Geological Survey for a series of tests to determine if the sillimanite could be concentrated to an acceptable grade within economic limits.

The rock is dark grey in color and consists of medium grained quartz, feldspar, biotite, muscovite, red garnet, and specular hematite, with coarser porphyroblasts of sillimanite ranging in length from ¼ to 1 inch. The sillimanite grains, as well as most of the other minerals, contain abundant inclusions of an opaque mineral which has tentatively been identified as the specular hematite previously mentioned. The average sillimanite content based upon grain counts of crushed rock has been estimated at 10 - 11%. Locally the gneiss has a lit - par - lit structure caused by the presence of numerous veins of biotitic aplite. Concentrations of sillimanite can often be observed along many of the vein - host rock boundaries.

Beneficiation Tests

Tests were conducted along three main lines and will be discussed below in the following order: (1) selective crushing and screening, (2) flotation, (3) table agglomeration.

Selective crushing and screening. A successful process of selective crushing depends on the presence of a mineral which is more resistant to comminution than the groundmass in which it occurs. Its resistance may originate in its shape, hardness, maleability, or degree of bonding to adjacent minerals in the rock. In liberating the desired mineral the crushing apparatus is adjusted so that the smallest opening through which all of the material must pass is as close as possible to the size of the mineral which is to be recovered.

The disk pulverizer which was used in this operation has a shearing action similar to a grist mill. The finer grains surrounding the sillimanite are sheared away because the interminerallic bonds are weaker than those within

[1] Trefethen, J. M. Report of the State Geologist, 1943-1944. Map XVI, p. 66.

the larger porphyroblasts. The action of the pulverizer however is so violent that a good percentage of the sillimanite is broken as well as the groundmass.

Since it was desired to recover as much of the sillimanite as possible in fragments 1/10 of an inch or larger, the rock was crushed to pass the #4 screen with as much as possible retained on the #8. The material retained on the #8 screen was recrushed 4 additional times with separation of the fines following each crushing. Each additional pass through the pulverizer resulted in an upgrading of the concentrate, however, at the expense of the total weight of sillimanite retained. To increase the recovery, the fraction retained on the #16 sieve was treated in a similar manner with closer disk spacing.

The combined concentrates amounted to 2½% of the original sample and were 80% pure, exclusive of the microscopic inclusions within individual sillimanite grains. Although the grade of this product might be satisfactory for certain refractories, the small ratio of recovery does not suggest that this method is economically practical.

Flotation. Flotation of the undersize product from the crushing and screening operation was attempted with moderate success but our work needs improvement to increase the quantity and quality of the concentrate.

A —30, +50 mesh product was scrubbed with NaOH for 15 minutes and decanted to remove —100 mesh slimes. The pulp was washed and conditioned at 50% solids with dodecylamine acetate and H_2SO_4, the former to collect the micas and the latter to depress the granular silicates. At a PH of 3 the mica float was 95% effective but the concentrate was contaminated with 1-2% sillimanite. The tailings were washed and conditioned again with Reagent 825, fuel oil, Frother 52, and H_2SO_4. The pulp was diluted and aerated giving an 8% concentrate carrying approximately 60% sillimanite and garnet, with the remaining 40% consisting of quartz and feldspar. The sillimanite in the concentrate represented approximately 70% of that available in the feed at this stage. Further scavenging and cleaning steps failed to improve the recovery.

Oleic acid was also used as a collector for the sillimanite but without very satisfactory results due to a lack of frothing ability at the low PH ranges necessary to depress the quartz with H_2SO_4. With the same collector sodium silicate failed to depress the quartz although a good froth resulted.

The fact that a fairly good concentrate of sillimanite was obtained suggests that more work should be carried out in this field, in an effort to improve the quantity and quality of sillimanite recovery. A step in this direction is the accumulation of literature and samples of reagents which have been found successful in the past by other workers.

Table agglomeration. Table agglomeration of silicate minerals is less used than formerly. However, the application of this technique to the Warren Sillimanite gneiss proved more successful than the preceding methods.

The process is essentially coating certain minerals making them water repellent and oil adhesive while not affecting the wetting properties of other minerals. In sillimanite agglomeration, oleic acid was used to coat the desired grains which were subsequently coated with heavy oil to clump the grains together.

The oiled particles are fed to a shaking table and subjected to a cross flow of water. This water washes the particles over the side by a combination of skin flotation aided by a decrease in specific gravity due to the oil coating. The non-oiled particles move along the riffles toward the discharge end of the table where they either pass to a scavenger table or are removed from the circuit.

In the tests, various sizes of feed were used but those which were more closely classified gave the best results. One sample was crushed so that 99% passed the 16 mesh screen. It was split into the following fractions by screening: +50 mesh, 61%; —50, +100 mesh, 19%; —100 mesh, 20%. The largest fraction was tested first and the tailings run over the table a second time to scavenge any remaining sillimanite. The combined concentrates were distributed as follows:

+30	40.7% wgt.	85%	sillimanite
+50	46.3% "	65%	"
—50	13.0% "	35%	"

The average sillimanite content of the coarse run concentrate was then in the vicinity of 69% with the major impurities being biotite and garnet. The concentrate represented 12.1% of the coarse fraction and after magnetic cleaning to remove iron bearing impurities, a final concentrate (95% pure) was obtained representing 8.6% of the sample.

The —50, +100 fraction was similarly treated on the table, the main difference in technique being the use of a shorter stroke and an increased number of strokes per minute. A concentrate representing 6% of the sample and averaging 70% sillimanite was obtained. The tailings from this step still carried 20% of the available sillimanite.

Because of the rather low values it contained, the —100 fraction was not processed, although with a further modification of the speed and stroke the values might be recovered.

Conclusions

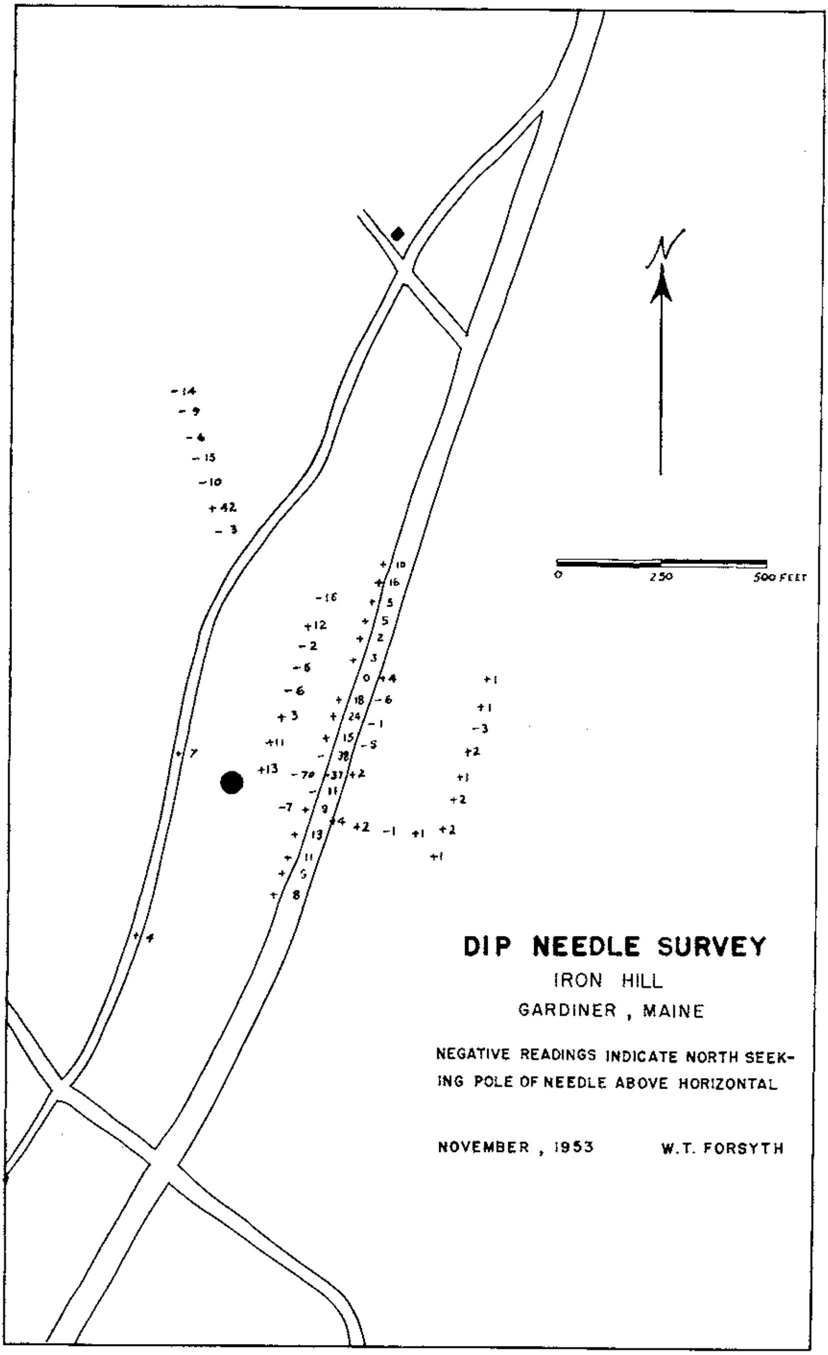
1. Sillimanite is completely liberated upon grinding to 50 mesh, with approximately 95% being liberated at 30 mesh. With this fact in mind, it would seem advisable to employ beneficiation methods which do not require finer grain sizes.

2. A crushing-screening type of beneficiation will recover a product running 80% sillimanite in the size range of —4, +16 mesh, but in such small amounts (2½%) that the rock could not be handled economically.

3. Flotation did not prove entirely satisfactory because of the low recovery and lack of selectivity. Since the main contaminants were quartz and feldspar, they could not be extracted magnetically. A better choice of reagents might improve the product.

4. Table agglomeration, being easier to control and capable of separating coarser material, was found most satisfactory, giving a concentrate 69% pure and representing 8% of the total sample.

5. Magnetic separation of concentrates from the flotation cell or the table is necessary in order to remove the iron bearing minerals and traces of tramp iron from the crushing equipment. Cleaning by this method leaves a concentrate of approximately 95% sillimanite. This non-magnetic residue still contains variable amounts of the fine grained hematite. Some grains contain only a fraction of a percent but the average content would be about 5 percent, bringing the total impurities in the concentrate up to approximately 10 percent.


N
0
250
500 FEET
DIP NEEDLE SURVEY
IRON HILL
GARDINER, MAINE
NEGATIVE READINGS INDICATE NORTH SEEKING POLE OF NEEDLE ABOVE HORIZONTAL
NOVEMBER, 1953
W.T. FORSYTH

PYRRHOTITE MINERALIZATION AT IRON HILL, GARDINER, MAINE

William T. Forsyth

INTRODUCTION

In relocating U. S. Route 201 southwest of Gardiner, Maine, a road cut was made through Iron Hill exposing a zone of sulfide mineralization which was examined in November, 1953 by the writer.

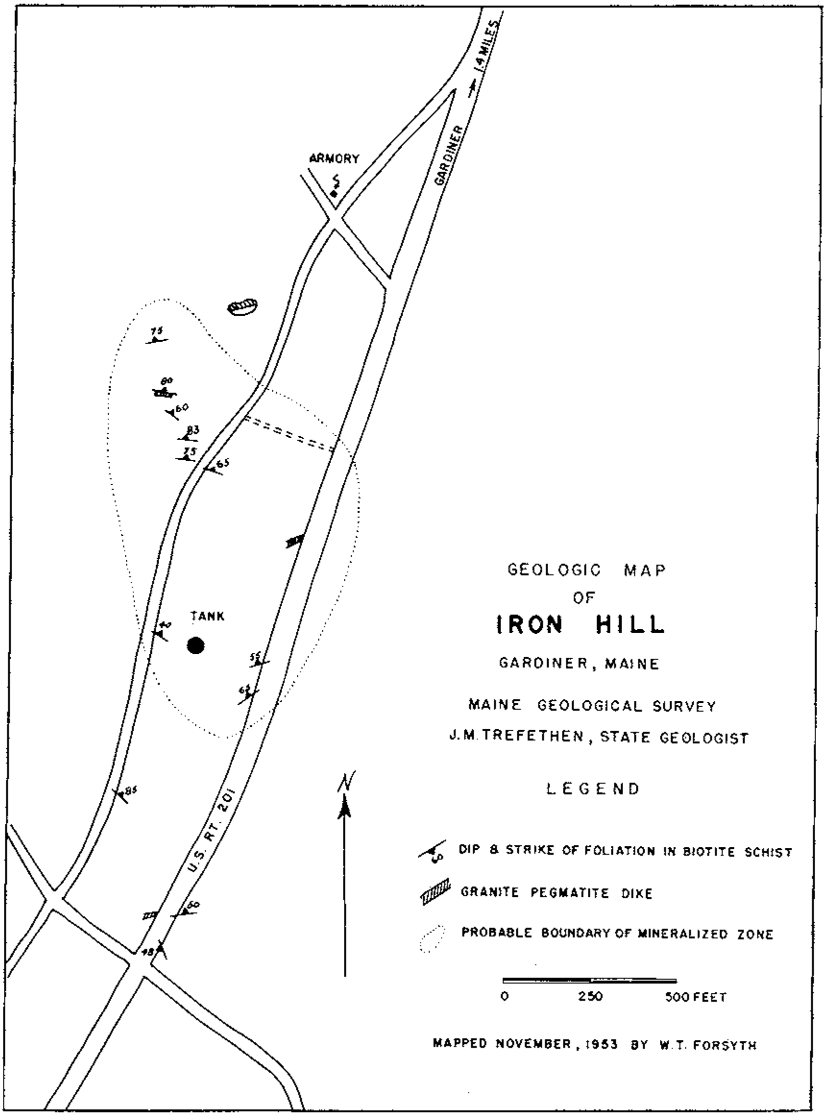
The origin of the name Iron Hill may be attributed to the presence of iron sulfides which cause heavy rust staining of the rocks and glacial drift in the area. Local residents report that attempts to mine the rock for iron ore were made during the 19th century but details of the operation are not available.

Field work consisted of sampling the cut over a distance of 600 feet and attempting to outline the zone of strongest mineralization by means of dip needle readings and physical observations of the rock (see maps).

Geology

The rock in the road cut is a biotite-garnet-quartz-feldspar schist intruded by medium grained granitic pegmatites of simple mineralogy as dikes and sills. At the southwestern end of the outcrop, the schist appears to grade into a biotite-granite gneiss. Five hundred feet southeast of the intersection of new Route 201 and Marston Road a highly contorted biotite-granite gneiss is found interlayered with simple pegmatites. This same gneiss was found in several places on Capen Road but could not be traced directly into the schist because of lack of outcrops.

Examination of the rock showed the sulfide mineral to be pyrrhotite occurring as disseminated blebs with irregular shapes. In addition to the disseminated grains, the pyrrhotite also occurs in narrow veins. Although faint qualitative tests for nickle were obtained in the laboratory, quantitative tests by commercial assayers failed to reveal the presence of this metal. Sulfides are also found in minor quantity within the pegmatites, and marginal to these dikes, commonly are coarser than in the rest of the schist. Local silicification seems to have affected the schist and within these areas the pyrrhotite occurs in greater quantity. Graphite is present in the rock as fine disseminated grains and also as clusters within the pegmatites.


GEOLOGIC MAP
OF
IRON HILL
GARDINER, MAINE
MAINE GEOLOGICAL SURVEY
J.M. TREFETHEN, STATE GEOLOGIST
LEGEND
DIP & STRIKE OF FOLIATION IN BIOTITE SCHIST
GRANITE PEGMATITE DIKE
PROBABLE BOUNDARY OF MINERALIZED ZONE
0 250 500 FEET
MAPPED NOVEMBER, 1953 BY W.T. FORSYTH
ARMORY
TANK
GARDINER
1.4 MILES
U.S. RT. 201
N

Dip needle readings were taken at close intervals near the area showing strong mineralization and at wider intervals in other parts of the area. The background reading hovers within 2 or 3 degrees on either side of the instrumental zero point. Readings in the gneissic area close to Iron Hill are in this order of magnitude but begin to rise in the vicinity of the road cut. About 250 feet north of the southern limit of the cut, the needle showed considerable abberation from its rising trend in that the north seeking pole which usually dips below the horizon was deflected above the horizon some 36°. At this station the instrument was then held in direct contact with the rock and a reading of 80° above zero was obtained. This negative reading ceased within 75 feet in a northerly direction where the needle assumed its normal position, gradually diminishing to its background reading. Because no significant changes in the amount of mineralization were observed in the immediate vicinity of the anomaly, the writer believes that a small concentration of pyrrhotite occurs at shallow depths below the surface and may be polarized, accounting for the reversal of dip direction.

WELL FINDING

Joseph M. Trefethen

Man has always had to find water. Surface supplies, streams, lakes, and natural springs were the most obvious sources. With development of engineering and engineering skills, although dating back beyond the dawn of recorded history, man learned to get water also by digging into the ground. Now water in very large volume indeed is brought up from beneath the surface for many public systems and for private industry as well as for individual homes. In fact water wells yield about 20,000,000,000 gallons a day at an estimated daily cost of $1,000,000 to water users in the United States.

Because underground water is out of sight, it became mysterious, and being mysterious became the subject of mythology and superstition. By the middle ages, perhaps earlier, some credulous and some sly dowsers had come to claim supernatural powers of water detection through the agency of forked sticks or other paraphernalia which served as props to befuddle uncritical, undiscriminating, possibly bemused dupes.

Occurrence and Movement of Underground Water

The presence and abundance of subsurface water are matters of observation. If there is water beneath the surface of the ground, there must be openings to contain it. The openings in which water is contained in rocks and soil, and through which it travels beneath the surface are:

1. Openings between the grains or pebbles of unconsolidated or partially consolidated soils and sediments.

2. Joints or cracks that divide rocks into blocks of greater or lesser size; in granites and similar rocks this is the only type of circulatory system.

3. Cavernous openings in soluble and some volcanic rocks.

The size and interconnections of the water-bearing openings determine the permeability of the material, and this property, *permeability,* together with the hydraulic gradient determine the velocity of flow. For non-turbulent flow, which prevails in the underground movement of water, an expression:

$$V = k \frac{h}{l}$$

known as D'Arcy's law, has been demonstrated, where V is velocity, k is the coefficient of permeability, and h/l is the hydraulic gradient.

The only considerable source of this underground water that we use is the infiltered precipitation, which sinks downward, under gravity, to the level of saturation of all the interconnected openings. This level of saturation, known as the *watertable,* must be reached by a productive well. When a well is pumped, the level of the water drops, the *drawdown,* so that the groundwater table is depressed in conical fashion around the well. This local depression of the watertable increases the hydraulic gradient in the well, and water flows into the hole. If the rate of pumping is too fast, the drawdown reaches the intake level of the pump, and the pump must be shut down until the well recovers. At a lesser pumping rate, the drawdown steepens the hydraulic gradient until the increased velocity of flow into the well balances the withdrawal. Obviously, the more permeable the material, the wider the apical angle and the gentler the slopes of the cone of depression.

Because of the relatively slow movement of water through the subsurface openings, the watertable tends to parallel the surface configuration of the ground in a rough way. The watertable, therefore, is generally closer to the surface in the low places, and deeper beneath the surface on the high places of the ground surface. In a protracted drought the level of saturation tends to lower and flatten out.

By introducing dyes into the ground water, and timing the arrival of the colored water into neighboring wells the rates and directions of subsurface circulation can be determined; and pumping data, yield, drawdown, and recovery rate give the raw material for engineering calculations.

The point of this brief discussion is simply that the occurrence of water underground is not mysterious, and that its movements are in accordance with the known principles of fluid mechanics.

Location of Underground Water

There are four ways of locating underground water supplies, practiced currently. These are: surface observations, test holes, geophysical methods, and hocus pocus. The first three of these methods are based on scientific principles. By observation of the surface configuration and materials, and of the distribution and attitude of the water-carrying structures and of the water levels in accessible places where the ground water level is shown, as by stream, swamp, lake, spring, or well levels, shrewd surmises can be made about the occurrence of subsurface water. Test holes may be put down for exploratory purposes if the requirements of volume are sufficient to justify this type of exploration, and tests made of yield and quality. In some places determination of the presence and attitude of water carrying structures has been made successfully by using surface measurements of the electrical conductivity of the rock or soil. Unfortunately, the hocus pocus method of water location that depends on the necromancy of a crotched stick or similar device is widely accepted or at least tolerated. The attitude expressed by many is, "I don't believe in it, but it works"! Others are militantly faithful.

All dowsers claim power to locate water underground. Some claim to discover only moving water, though none has set the lower limits of motion required for perception. Most claim ability to determine depth of water; some soothsay yield. For all dowsers a springy crotched object, stick, wire, or other device nods at the underground "vein". This observer has noted pine, witch-hazel, apple, peach, hickory, hemlock (quality of water doubtful), alder, willow, and elm used. Depths are estimated by a variety of ways. The crotch twirls in the hands a number of times corresponding to the depth of water (in feet, engineers note conversion factor to metric units). When asked verbal questions the stick "nods" yes or no; it jiggles up and down the number of times corresponding to the depth, again in feet. When walking backwards from the point of discovery the stick goes down again when the backwards walk equals the depth. We are seriously solicited to accept these methods as science in action.

Not all, but a significant minority, claim other powers of divination by the stick — ability to distinguish whisky from water, beer from champagne, silver from copper, the sex of unborn children, the location of missing objects alive or inanimate, or the results of an unplayed horse race, heretic from faithful. In spite of these patently fatuous or deliberately fraudulent claims, residual faith in the powers of the dowser and/or stick testify that although surprisingly few major miracles have happened since the middle ages, minor ones are passed every day by the minor prophets of the rod.

The most vehement and silly dowsers even claim powers to locate underground water by waving a crotched wand over a map. It appears that those who practice this map magic would necessarily conclude that the force of attraction increases directly with the square of the distance, and inversely with the products of the masses involved! This may be fortunate, however, for this extravagant reversal of physical law has done much to discredit dowsing. Witness the witch in Australia teledowsing Bermudian water.

Examples of Dowsing

In association with Dr. Gardner Murphy and under the auspices of the American Society for Psychical Research, the author had opportunity to observe some thirty dowsers in action. An area of glacial outwash of somewhat uneven surface and diverse cover was selected for the field trial. The dowsers, blindfolded, were conducted to the area, and allowed to wander, blindfolded, until they encountered a major subsurface " vein ". In an area of some 40,000 square feet, over which all were conducted, there was neither coincidence nor concentration of points selected by the blindfolded dowsers. Once a point was indicated by a dowser, the same blindfolded operator was conducted over the same point again and again; no further indication was received, however, after the initial one, by a single one of the group at or close to the same spot. Similarly, with blindfold removed, the points selected by the individual dowsers showed neither coincidence nor concentration. Following the location of points which were mapped instrumentally without leaving pegs in the ground to distract the subsequent dowsers, the two points selected by each dowser (one blindfolded, one eyes open) were reoccupied, and well points driven, the depth of the watertable measured, and the holes pumped for yield. There was no accordance of estimated depth with fact, and the estimated yields were even further from actuality. The results demonstrated only one thing clearly; among that particular group of thirty there was not one who evidenced any unusual power, although each member of the group was a professional or subprofessional member of the dowsing clan. The age, educational, and economic status of the individuals tested were as varied as the points they selected.

After seeing some hundred odd dowsers at work, the group tested in the field, as just related, seem to me to be typical. I am willing to concede to the argument, " Of course you were not able to find any good dowsers in the lot if there weren't any in the group." I further submit that I have yet to see a dowser that does show any unusual talent other than a good eye for terrain.

Another rather interesting experiment was conducted under the supervision of Dr. Murphy. A cardiagram was obtained while a dowser was locating underground water. Immediately preceding each nod of the stick a bump in the curve indicated an acceleration of the beat. This was interpreted by the proponents as indicating some mysterious incitation by some unknown force acting in an unknown manner through the stick on the hypersensitive dowser. A criminal investigator, using similar equipment, might have concluded that the subject was activated at the moment to tell a whopping big lie.

How does the rod work?

There is no question in any mind, reasonable mind, that the stick is muscularly activated. Moving pictures of dowsers in action demonstrate the muscular activity beyond question. Further, if the pull on the stick is external, it would bend beyond the fulcrum of a support placed under the rod. Such distortion has never been observed. If the stick is placed over the back of a chair, for example, it will respond in the hands of the dowser, but it is easily seen that it does not bend over the chair back but is pushed up by the hands of the dowser. The real question is whether or not there is a stimulation received through the rod that causes a muscular response by the dowser. It appears to me that for those dowsers who are honest, there is a stimulation of the same category as received by a ouija board operator, an expected and consequently received "message" that has nothing to do with water; a subjective, possibly involuntary, muscular response accentuated by the unstable equilibrium of the crotched stick results. Other dowsers, under no delusion as to the power of the rod, or of their own hypersensitivity, but with an excellent eye for terrain are perhaps among the more successful. It appears probable however that the intermediate group, with full faith in their powers and that of the rod but with much experience in the field subconsciously receive their "stimulus" visually from external surroundings.

Why does the rod work?

The last question to consider here is, Why is it that dowsers are almost always successful in locating water? The answer is not far to seek. In a humid region with a water table related to the ground surface, the chances of failing to find water at any given place are about one in ten. With these overwhelming odds in his favor, it is little wonder that the dowser is successful. In a horse race of ten entries if there were seven winners one place and one show to pay off with only one loser, it would be difficult to lose. In fact one dowser I met guarantees success. No water in the well, no fee for the dowser!

LIGHT WEIGHT AGGREGATE IN MAINE

by

JOSEPH M. TREFETHEN

Light weight aggregate production for construction forms and blocks is big business. Over three hundred plants for production of this structural material are operating in the United States, and the industry is rapidly expanding to keep pace with added demands. In California — the leading state, forty-one plants are listed. However, there is but one plant listed in northern New England (Maine, New Hampshire, Vermont); if census data by Pit and Quarry Publications, Inc. are correct the plant at Veazie is our only producer; this plant uses cinders from outside the state.

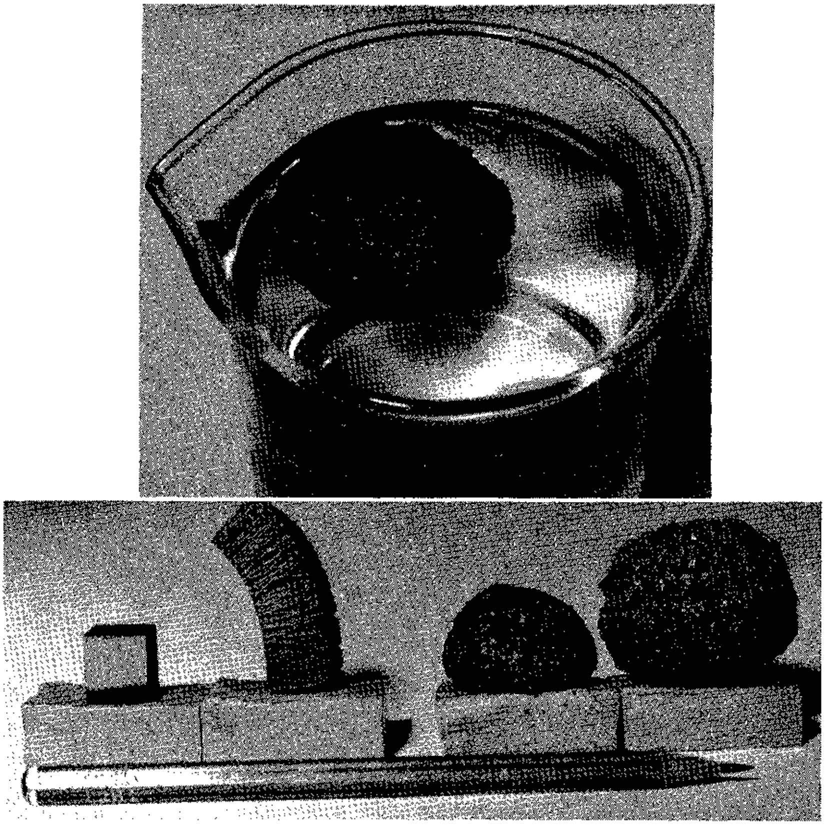
By definition of the American Society of Testing Materials, light weight aggregates passing a ⅜ inch screen must weigh less than seventy-five pounds per cubic foot, and those that are retained on a ⅜ inch screen cannot exceed fifty-five pounds per cubic foot. The properties desired are lightness of weight, strength, low absorption, and both chemical and physical stability, and good size and shape grades for workability, and of course, low cost of production.

The raw materials can be divided into naturally or primarily cellular and those in which vesiculation is induced for the production of aggregate. Primarily cellular materials are volcanic pumice, cinders, scoria, and diatomite. Secondarily vesiculated for this use are expanded clay, shale, slate, perlite, vermiculite, and slag.

In Maine are no naturally or primarily vesiculated lavas, as pumice or scoria, nor are there large tonnages of diatomaceous earth. Bloatable slates, and clay do exist, however, and may become the basis of a sound business.

The bloating of such materials as slate for example depends on the formation and expansive action of gas on intense heating and partial softening of the rock. Not all slates or shales, or clays are bloatable. Impurities supply the gas, water, carbonates, and iron compounds (as pyrite), and possibly others supply the expansive gases that bloat most of the shales and slates.

If the gas is formed and violently escapes before the rock softens, the rock shatters; if the rock becomes too fluid before the gas is liberated, the melt sticks to the kiln. There is necessary thus a favorable range of bloating temperature required.



Expanded Maine slate from Monson-Brownville slate belt. In lower figure original size before bloating on left of each pair.

Maine does have slates and clay that will bloat. *Figure 1* shows the effects of heat on a slate from the slate belt that runs through Monson, Maine. This took place at a temperature between 950 and 1100 C. The tests necessary to evaluate the material as suitable for a new industry however, have not yet been made. The questions that must be specifically answered are of two categories — those of human economics, and those of the characteristics of the material itself. The questions are:

1) Will the material bloat? Tests in a stationary furnace, as those made in our laboratory can answer this question. Mere bloating however is not

enough; tests of full-sized charges in a rotary kiln often differ from those of small tests in a stationary furnace.

2) What is the bloating temperature? It is necessary that there be a range of temperature between the softening and sticky stages, during which gas is evolved in volume and violence enough to expand the material. It is impracticable to bring a furnace to an exact degree, no higher or no lower with a continually moving charge of rock. Such control if necessary would be prohibitively expensive.

3) What size of pre-bloat crushing is most satisfactory?

4) What is the bloat good for? Will it give the necessary lightness and strength, insulation, mixability, and other properties according to the specifications for a particular use?

On the other hand, and no less important are the economic questions:

1) What will it cost to produce the material, raw material, fuel, labor, overhead and equipment, and similar items?

2) What is the market? Transportation charges, sales costs and the like. must be considered.

If these questions are answered satisfactorily, one other question immediately arises before plant construction, Is there a better or more economical source of raw material, or one more fortunately situated?

The State Geologist wishes to point out the substantial savings effected in some types of public construction as well as to bring to attention a presently unused resource. One example of public savings will do: it is reported that by using light weight aggregate instead of conventional sand-gravel in the concrete roadway of the San Francisco-Oakland bridge, over three million dollars were saved in structural steel costs by the lightening of the structure.

RESURVEY OF A PORTION OF THE DESERT OF MAINE

by

HENRY W. ALLEN

Due to widespread interest in the dune area known as the Desert of Maine, Freeport, Maine, the Maine Geological Survey first mapped a portion of it in 1946.[1] In the initial survey an area greatly affected by strongest winds was chosen. At that time it was felt that by periodic remapping of the same area, a measure of the effectiveness of wind action in the region could be made.

A plane table resurvey (see map at back) was made in August 1953. The boundaries and elevations of the sand area were carefully checked relative to markers established by the original survey. A comparison of the two maps shows only slight extension of the boundaries. The greatest advance was noted in the southeast, south and southwest portions. In the extreme south portion approximately six feet of forward movement was found to have occurred in seven years. This reflects the effect of strong northerly winds in the Spring and Fall. More apparent, were changes in the configuration of the dunes themselves. In places appreciable heightening has occurred, whereas in other places dunes have been lowered or shifted to new locations.

The sand available for extension and buildup of dunes can be clearly seen as being derived from areas where sand elevations are lowering by wind action, rather than from any "boiling-up" activity which some people have contended. The greatest lowering of the mapped area has occurred in the vicinity of the clay butte.

As the sand elevation is lowered to a point near the water table, the sand remains moist for a period of time allowing moss to establish itself. In due time small birches and pine are seeded with the result the area becomes naturally reclaimed. Many acres of land in the central lower parts of the "desert" have been reclaimed in this fashion.

At the present time it appears that the amount of area being reverted to forest is at least keeping pace with that being lost to encroaching sand. We need not fear that Maine will become a desert wasteland within the next few generations.

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[1] Trefethen, J. M., "The Desert of Maine", Report of the State Geologist 1947-48, March 1949.

A SURVEY OF SEVERAL REPORTED DIATOMACEOUS EARTH DEPOSITS IN MAINE

HENRY W. ALLEN, ELBERT S. PRATT

Diatomaceous earth deposits in Maine are, for the most part, located in small, swampy ponds and bogs, and where possible, boats were used in making soundings and taking samples.

The apparatus for sounding and sampling consisted of a brass, peat auger with enough sections of pipe to make soundings to a depth of about 20 feet. This instrument was generally satisfactory although, occasionally, the diatomaceous earth was so compact that difficulty was experienced in its use, as at Hid Pond, Kingfield.

The following ponds and bogs were visited in Maine:

Chalk Pond	Albany
Hid Pond	Kingfield
Chalk Pond	Beddington
Duck Pond	South Waterford
Duck Pond	Columbia
Umbagog Lake	Maine - New Hampshire border
Perley's Meadows	Naples
Bog Brook Swamp	Monmouth

Swamp — on property of Russell Wensell — Andover

Of these areas, the largest deposits were at Hid Pond, Kingfield, estimated volume 35,000 cubic yards, and Chalk Pond, Albany, estimated volume 30,000 cubic yards.

CHALK POND: ALBANY, Bethel Quadrangle, is located 2½ miles northeast of the village of North Waterford on the properties of Ernest Wentworth, Harry Brown, and Chester Holt, all of North Waterford.

Description

Chalk Pond is elongated in a general north-south direction and had an area of over 10 acres. Soundings made from a row boat show a deposit of white diatomaceous earth in the southern quarter of the pond. This deposit lies in the area just to the south of the outlet. (See fig. 1) Here the pond is about 300 yards across in an east-west direction tapering southward to more or less of a point. In a north-south direction the deposit is about 150 to 200 yards across. The depth of the diatomaceous material varies from 2 to 4 feet at the edges of the pond to as much as 6 feet in the center of the deposit. Two to three feet of water was covering the area. Over the rest of the pond a thin layer of brownish, impure diatomaceous earth covers a brown ooze of silty, decayed plant material to depths up to 15 feet.

Estimated Volume

It is estimated that this pond contains 30,000 cubic yards of diatomaceous earth.

Accessibility

The pond may be reached by following a fairly good country road 2¼ miles from State Highway 25 at North Waterford to the farm of Harry Brown. The pond lies just 0.1 mile south of the road.

SKETCH MAP OF CHALK POND
ALBANY, ME.

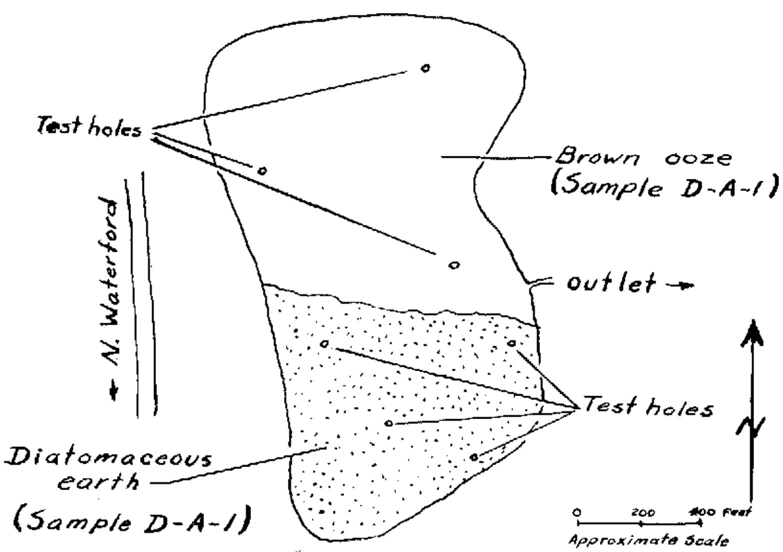


FIGURE 1

Drainage

The pond can be drained by digging a few hundred feet of ditch at the outlet.

HID POND: KINGFIELD, Dead River Quadrangle, is located in the eastern part of the township of Kingfield 1 mile south of Butler Pond on the property of Mr. Boynton, manager of the H. G. Winter Company store in Kingfield and Mr. E. Wing, also of Kingfield.

Description

Hid Pond is roughly oval in shape, extending in a northwest-southeast direction, and covers an area of approximately 10 acres. (See fig. 2) Three islands lie on a line extending north-east southwest across the middle of the pond dividing the pond nearly in half. These islands appear to serve as the western boundary of the firm, white diatomaceous earth, which extends east and south to the shore, including this whole area except for the cove located

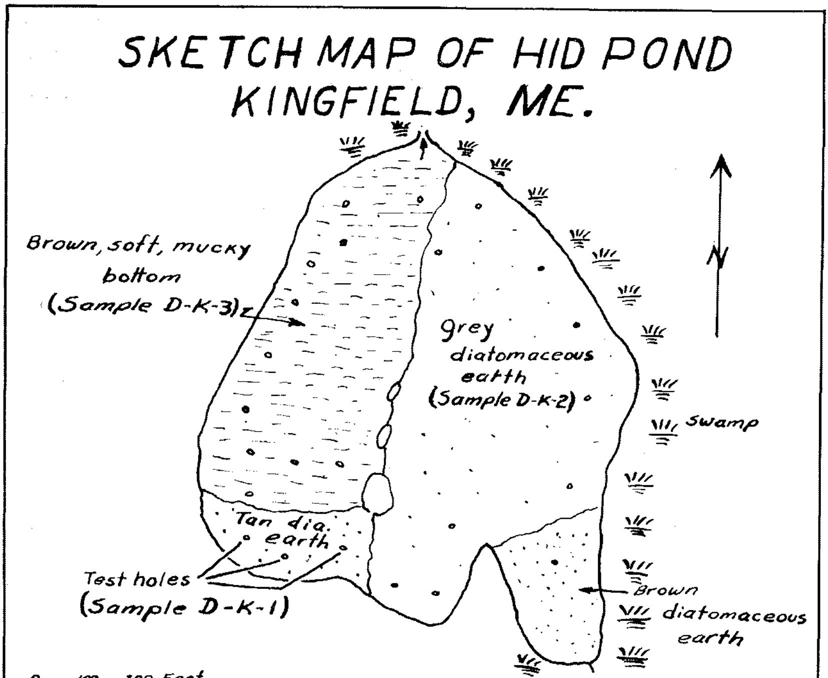


FIGURE 2

in the southeastern part of the pond. In this cove the deposit is not as firm and white as the rest, although it is an impure diatomaceous earth. The diatomaceous earth extends northward beyond the line of islands as a firm white material nearly to the outlet. To the west and northwest of the islands is a soft ooze.

It is estimated that nearly ⅔ of the lake area contains diatomaceous earth varying in depth from 8 inches to nearly 3 feet. The firm diatomaceous earth was not completely penetrated with the peat auger, because the depth of the water where the soundings had to be taken made it almost impossible to sound in the same hole twice. For this reason it is believed that the material is actually thicker in many places than the recorded 3 feet.

The area to the southwest of the line of islands contains diatomaceous earth of a tan-grey color indicating the border zone between the white diatomaceous earth and the peaty ooze.

The major part of the bottom of the western part of the pond consists of a soft brown, mucky ooze. In places the depth of this material was over 10 feet under 10 feet of water.

The pond is spring fed with no inlet. The depth of the water, controlled by a beaver dam at the outlet, varies from 3 feet to 10 to 12 feet. Drainage could be accomplished by removing the beaver dam at the outlet and digging a few hundred feet of ditch.

Estimated Volume

It is estimated that there is at least 35,000 cubic yards of diatomaceous earth in this pond.

Accessibility

Hid Pond is accessible from State Highway 16 at "Lexington Flats," Lexington Plantation over, first of all, 2 miles of poor country road. This is followed by 1½ miles of washed out road impassable to motor vehicles, as far as Butler Pond. From this point there is a trail in to Hid Pond, 1¼ miles to the south, which was used during the winter of 1946-47 as a truck road. Throughout the length of the prospective route there are many washed out places and swampy sections which would require filling and bridging before it could be put to use the year around.

CHALK POND: BEDDINGTON, Lead Mountain Quadrangle, is located on the boundary between Beddington and T 22, ½ mile south of the intersection of State Highway 9 and State Highway 193.

Description

Chalk Pond is about 20 acres in area. In the marshy ground on the southwesterly side, elongated in the north-south direction is a shallow channel filled with water and several smaller ditches, probably the result of dredging operations. To the south of this channel on land reported owned by Henry Mitchell's heirs is the remains of a plant for refining and drying diatomaceous earth. This plant was reported to have been in operation in the 1890's.

Soundings indicate that the diatomaceous earth is located in the shallow water and swampy areas along the southwest side of the pond. (See fig. 3) However it does not seem to extend out into the deeper water of the pond or into the swamp at the south end of the pond. The deposit stretches about 250 yards along the west shore, while at its greatest width, the south end, it is about 50 yards wide. This tapers to about 25 yards at the northern end. This whole area is said to be in the 27 acres owned by the Mitchell heirs.

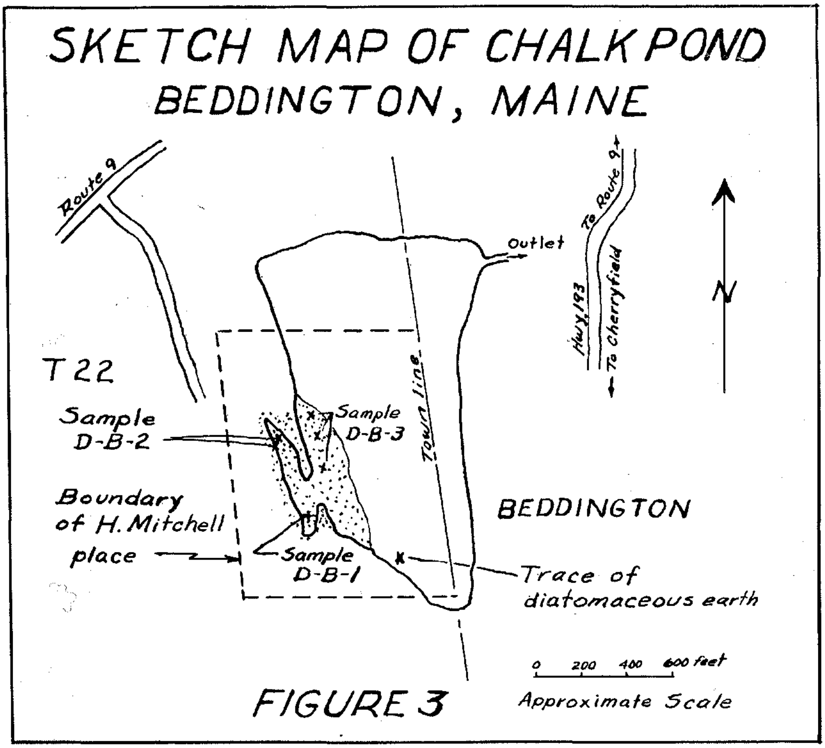


FIGURE 3

In the southern end of the dredged channel there is a good grade, white diatomaceous earth topped by a thin layer of brownish material composed of diatomaceous earth and other organic material. The thickness here is 1½ feet.

The northern part of the channel revealed 2 feet of diatomaceous earth of pulpy texture, more grey in color than in the southern section of the channel, and containing some brownish layers.

East of the channel, along the edge of the swamp on the pond side, the diatomaceous earth is generally brown in color and contains much grass and vegetable matter. The depth of the deposit here is 3 feet.

Soundings in the southeast section of the pond showed a trace of diatomaceous earth. The eastern and northern sides have gravel bottoms.

The depth of the water over the deposit varies from 1½ to 4 feet. The pond could be drained or lowered appreciably by ditching the outlet.

Estimated Volume

The volume of diatomaceous earth in Chalk Pond is estimated at 3000 cubic yards. However, careful sampling along the western side near the old channel may show a considerable additional volume.

Accessibility

The west side of the pond, where the diatomaceous earth is located, is accessible over an unimproved road from State Highway 9 about 1 mile southwest of the intersection of Highways 9 and 193.

DUCK POND: SOUTH WATERFORD, Fryeburg Quadrangle, is located about 3 miles northwest of the village of South Waterford on the property of Irving Morey.

Description

Duck Pond is approximately 6 acres in area with wide, swampy fringes which are very unstable. The pond is about 400 yards long, in a northeast-southwest direction and about 200 yards wide at its widest point.

No boat was available and walking around the edges was both difficult and hazardous due to the matted grass extending 20 to 30 feet out over the surface of the water.

Soundings along the southeast side of the pond showed a grey diatomaceous earth 2 feet in depth. In order to make a complete survey of this pond, it would be necessary to bring in a boat.

Drainage could be accomplished by removing an old dam at the outlet at the south end of the pond.

Estimated Volume

Since the extent of the diatomaceous earth could not be determined, no volume estimate was made.

Accessibility

Duck Pond can be reached over a fair country road leading northwest about 3 miles from a road intersection 1 mile southwest of the village of South Waterford. The pond lies 0.2 miles southwest of the road, in pasture land that is pretty well grown up.

DUCK POND: COLUMBIA, Cherryfield Quadrangle, is actually the northernmost of two pairs of ponds located 1 mile north of East Base of the U. S. C. and G. Survey Base Line in the northern part of the township. This northern pair of ponds, called Duck Pond, is on the property of Lloyd Drisco of Millbridge.

Description

Duck Pond occupies a large kettle hole which is separated in the middle by a glacial drift barrier, on the glacial and moraine known as the Blueberry Barrens. Each part of the pond has an area of about 5 acres. The southern part is at a higher elevation and drains into the northern part. In a small cove in the northern part of the pond there was some grey diatomaceous earth with more that was brown and silty. The work had to be done along the shore as there was no boat so that a complete survey could not be made. However, the cove in which the diatomaceous earth was located is about 16 yards across and 16 to 20 yards long. The depth of the diatomaceous earth near the point of the cove is 1½ to 2 feet. Between the cove and the outlet at the north end of the pond there was only a trace of the diatomaceous earth.

Work around the edge of the pond was difficult both because of the high water and because of the grass matting that had grown out over the surface of the water in some places. If further surveying in this area is carried out it is suggested that a boat be taken in to the pond by truck over the local truck road across the Barrens from East Base.

Estimated Volume

There appears to be at least 300 cubic yards of diatomaceous earth in the small cove in the northwestern part of the pond. This estimate may fall short of the volume of material available. Further soundings over the area of the pond would be necessary to determine this. However it would appear that the deposit is small.

Accessibility

Duck Pond can be reached by a winding truck road across the Blueberry Barrens leading generally northward from East Base of the U. S. C. and G. Survey Base Line for a distance of a little over a mile.

UMBAGOG LAKE: MAINE-NEW HAMPSHIRE BORDER, Milan and Errol Quadrangles, is located in the townships of Upton and Magalloway T 5 R 1, Maine, and Errol and Cambridge townships, New Hampshire. The Brown Company of Berlin, N. H. is the principal owner of the woods land surrounding the lake.

Description

Umbagog Lake is very irregular in shape, 7 miles long in a north-south direction, and varies in width from ½ mile to nearly 3 miles with many coves and inlets indenting the shore. The lake is relatively shallow, being less than 20 feet deep over the most of its area. A motor boat was used on this survey.

The party spent one day checking the coves and inlets along the Maine shore from Pine Point at the upper end of the lake to the south end of the lake, including Spillman cove, Glassby cove, B Brook cove, Tyler cove, and the shallow southeastern cove 1 mile northwest of the village of Upton without success.

Diatomaceous earth has been reported in Umbagog Lake in Hitchcock's "Geology of New Hampshire," vol. 3, Pt. 5, p. 92, 1878.

Accessibility

Umbagog Lake is accessible in Maine from State Highway 26 at Upton by an improved road to the southeast most cove of the lake. From New Hampshire, the lake is accessible by a 5 mile trip from Errol up the Androscoggin River, which is the outlet of the lake.

PERLEY'S MEADOWS: NAPLES, Sebago Lake Quadrangle, is located about 3 miles directly west of Naples village on Muddy River which empties into Sebago Lake.

Description

Perley's Meadows is an irregular shaped swampy area 1 mile long and ¼ mile wide. This area at one time was mowed yearly but has not been cut for quite a number of years. Much of it has grown up to bushes and at the present time is flooded to a depth of 1 to 2 feet, due to a beaver dam across the outlet. No boat or canoe was available and sampling along the center of the western edge of the swamp showed ½ inch of white diatomaceous earth on top of silty brown earth. It would appear that the quantity of diatomaceous earth is very limited.

BOG BROOK SWAMP: MONMOUTH, Livermore Quadrangle, is located on Bog Brook near the Monmouth-Leeds town line on the road from Curtis Corner across to Monmouth village.

A drained lake report was checked through several old residents of Monmouth without success. They suggested that the most likely location would be Bog Brook Swamp which drains into Androscoggin Lake.

Two soundings along the highway — the bog was too soft to walk across — in the southern part of the bog revealed about 3 feet of good peat on top of 3 to 6 inches of blue-grey clay, beneath which is more peat. No diatomaceous earth was found.

ANDOVER BOG: on property of Russell Wensell, ANDOVER, Rumford Quadrangle, is located 1½ miles northeast of Andover village on the properties of Russell Wensell, and R. Swain, both of Andover, and Warren Abbott of Rumford Center.

Description

Andover Bog is a 100 acre bog, where, by verbal report, diatomaceous earth is supposed to be found.

The survey party secured a canoe for use on the dead water of the bog but was unable to get it closer than ½ mile from the bog. Walking over the bog was impossible due to high water and the soft condition of the ground.

A test hole on the eastern edge of the bog on the property of R. Swain showed 10 feet of good peat on top of a gravel bottom. No diatomaceous earth was discovered.

Mr. Russell Wensell, an owner, reported that prior surveys had been made further into the bog and had revealed 10 to 12 feet of peat on top of 11 to 12 inches of bluish grey material, possibly marl or clay.

SUMMARY

1. All deposits of diatomaceous earth found by the survey party seemed small. The two largest ones were Chalk Pond, Albany, 30,000 cubic yards, and Hid Pond, Kingfield, 35,000 cubic yards.
2. All the deposits were found in bogs or small boggy ponds.
3. All important deposits were located in the southern or southeastern part of the pond or bog, except for the Chalk Pond, Beddington deposit which was in the southwestern part. The rest of the area was filled with silt, peat, or decaying vegetable matter.
4. No deposit was found to be over 6 feet thick, while the average thickness is 2 to 3 feet.
5. Many of the deposits are away from roads and other transportation facilities necessitating road construction or improvement before the material can be gotten out.

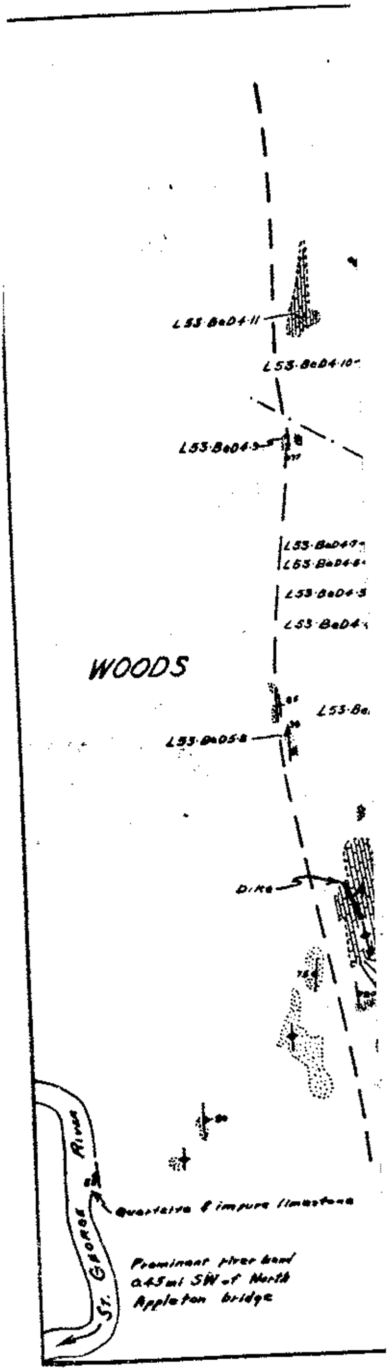
CONCLUSIONS

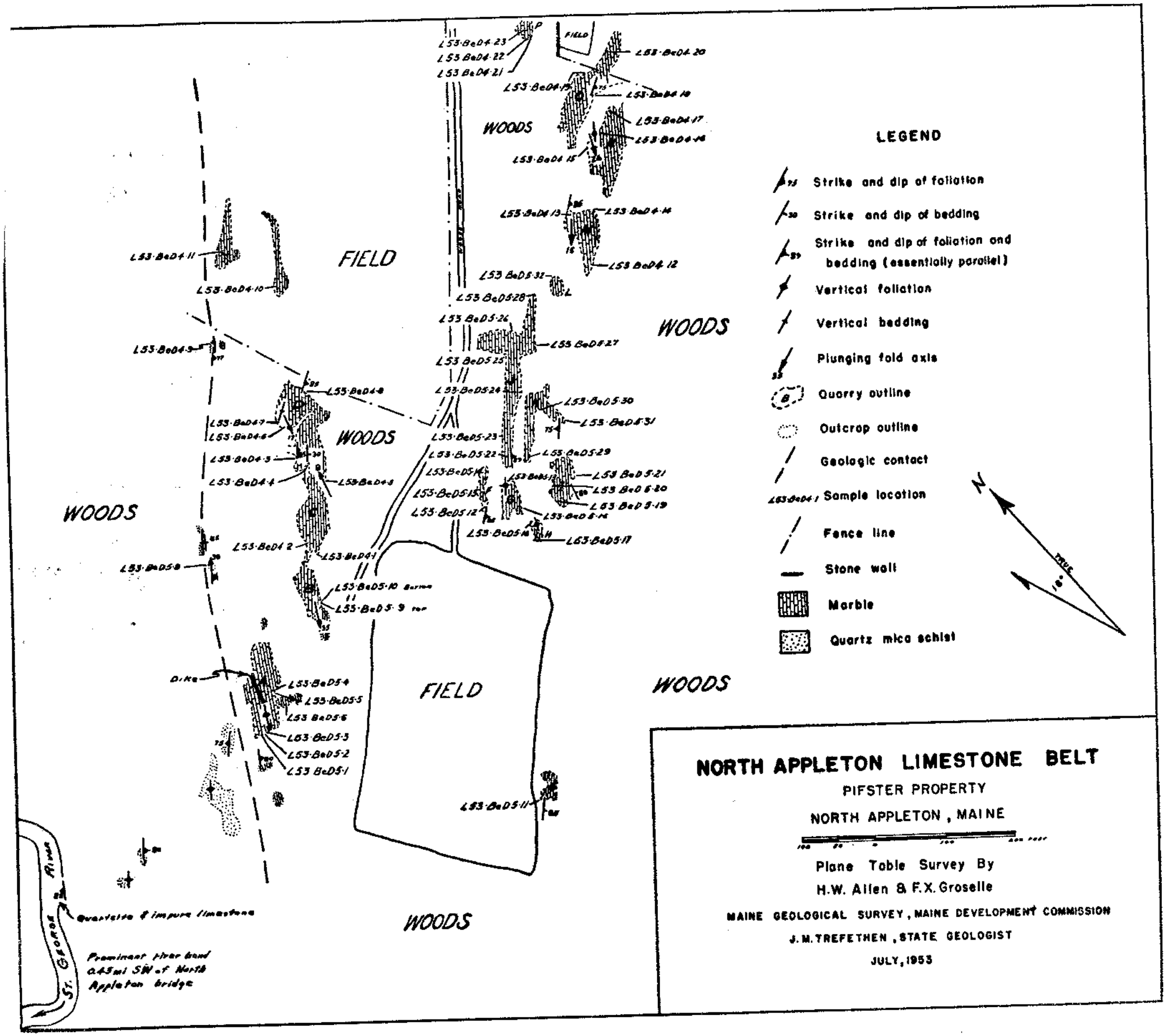
In as much as most of the diatomaceous earth deposits appear to be small and are often far from existing transportation facilities, it would seem that it would not be worth while to work them. However, in some cases, the deposits of diatomaceous earth might be worked in conjunction with peat deposits which often occur with it.

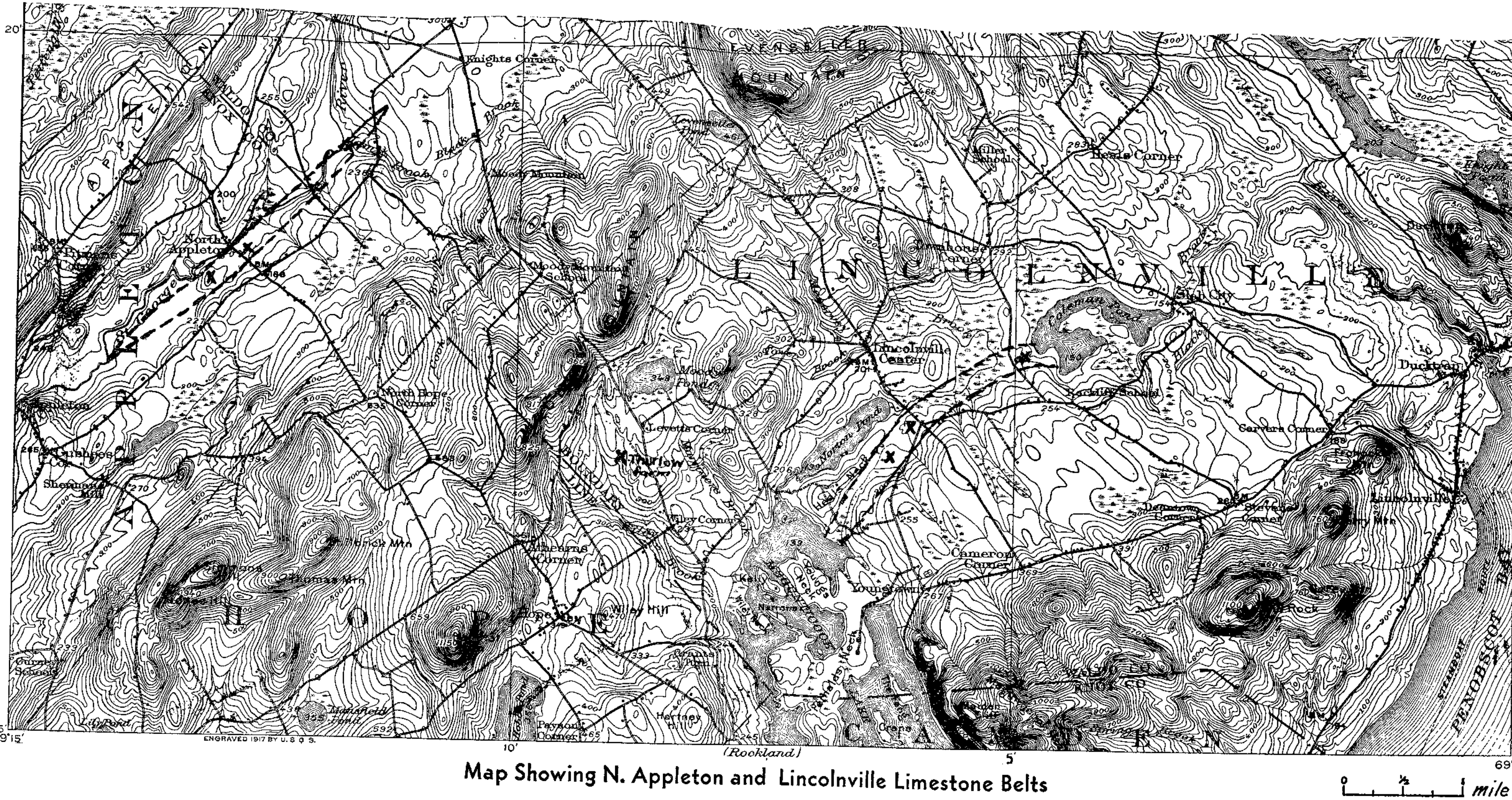
It is the opinion of the survey party that, of all the locations visited, Chalk Pond in Albany is the best source of diatomaceous earth considering volume, accessibility, and ease of drainage.

Hid Pond in Kingfield, containing the largest deposit of any area visited, may contain sufficient diatomaceous earth to warrant building 3 miles of road. Here it should be noted particularly that the entire thickness of the deposit was not penetrated. Therefore calculations made from areas and measured thicknesses must underestimate the actual volume.

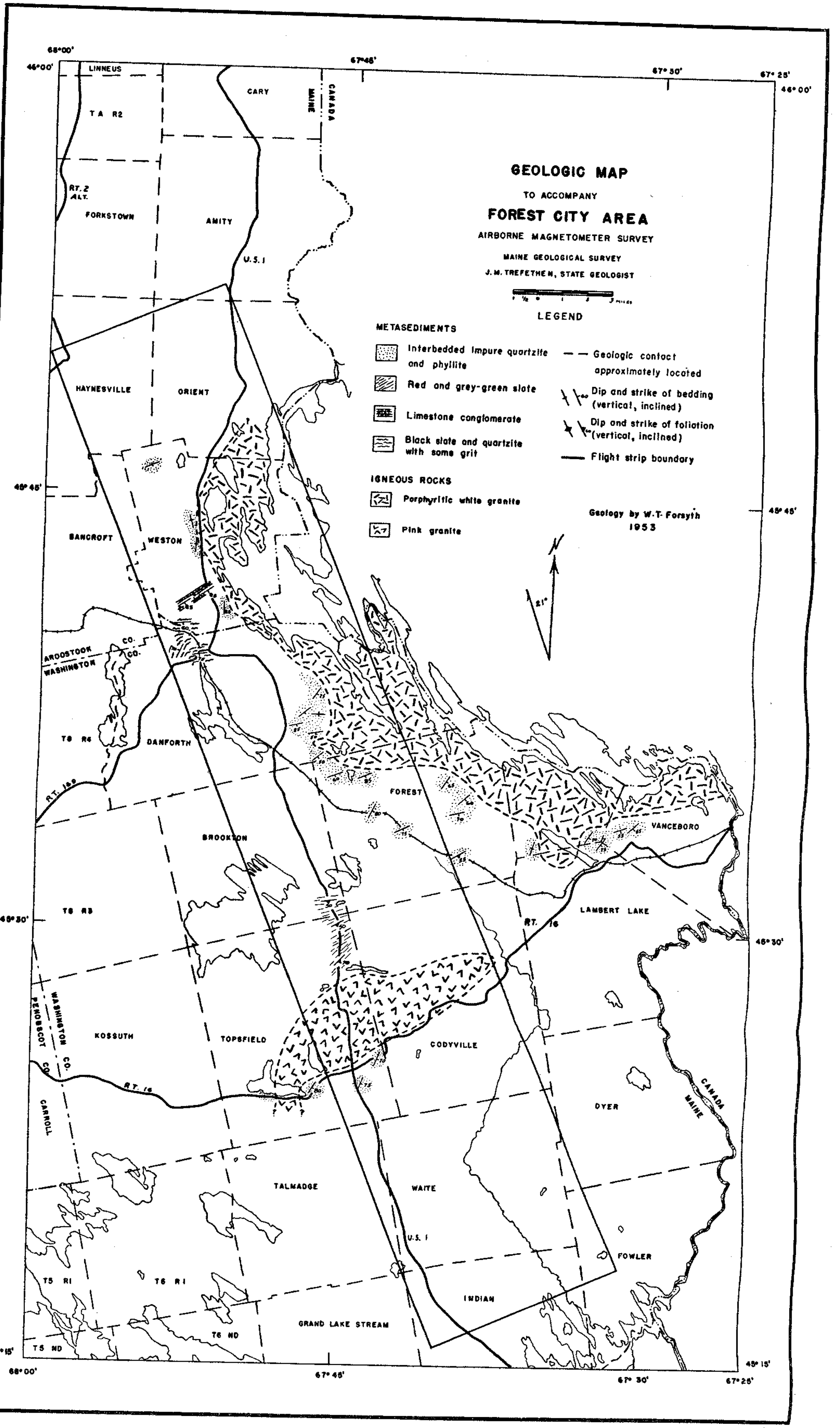
The survey party confined its sampling for the most part to the pond bottoms due to the brief time available for the examination. Bottom sampling does not preclude the occurrences of diatomaceous earth beyond present limits of the ponds. Much filling with both organic and inorganic matter has taken place over the period of 10,000 to 15,000 years since the end of the last glacial stage.

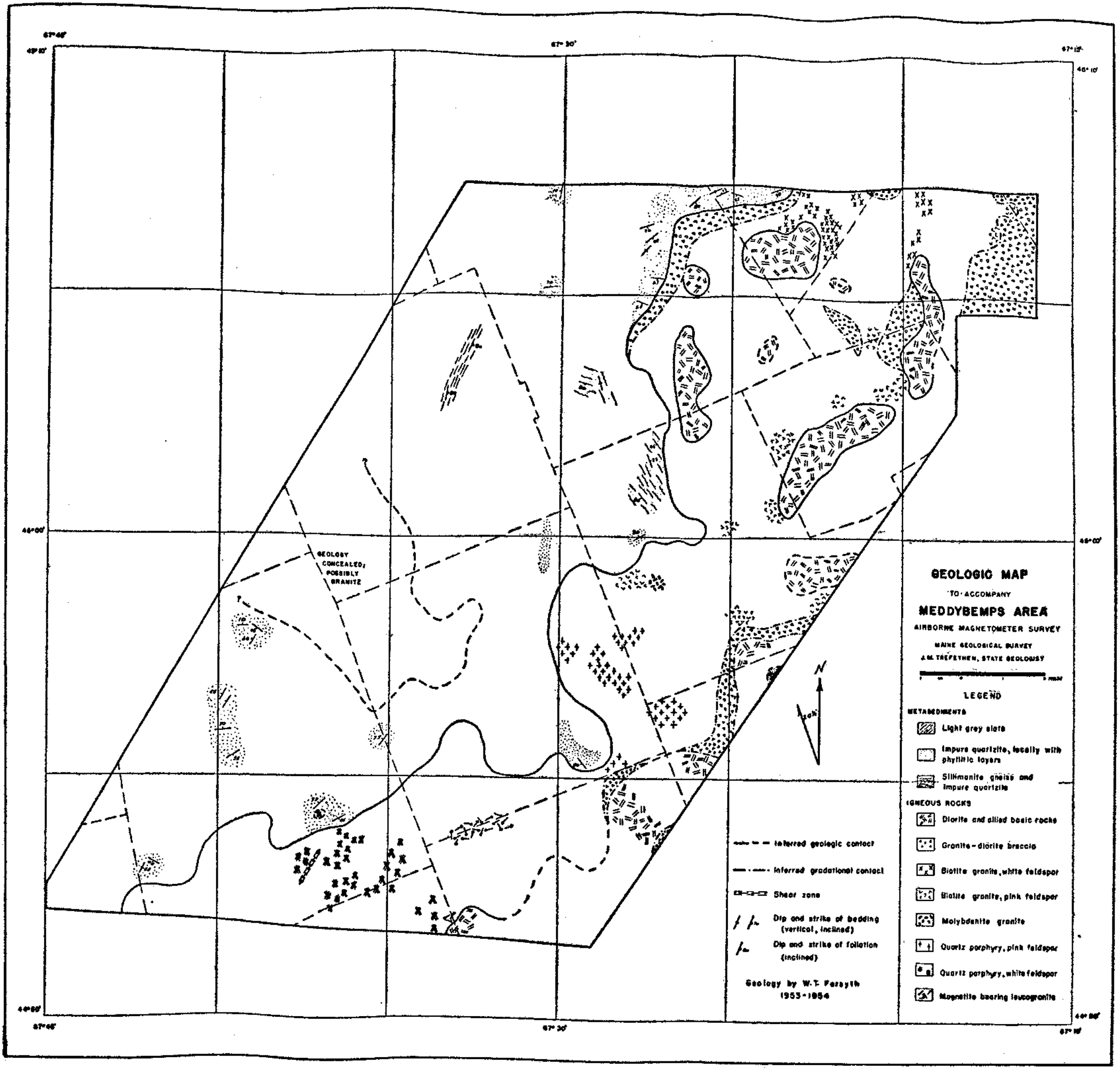

L53·BeD4·11
L53·BeD4·10
L53·BeD4·5
WOODS
L53·BeD5·8
Dike
St. George River
Quartzite & impure limestone
Prominent river bend 0.45 mi SW of North Appleton bridge


LEGEND
Strike and dip of foliation
Strike and dip of bedding
Strike and dip of foliation and bedding (essentially parallel)
Vertical foliation
Vertical bedding
Plunging fold axis
Quarry outline
Outcrop outline
Geologic contact
Sample location
Fence line
Stone wall
Marble
Quartz mica schist
N
TRUE
18°
FIELD
WOODS
FIELD
WOODS
WOODS
FIELD
WOODS
WOODS
Dike
St. George River
Quartzite & impure limestone
Prominent river bend 0.45 mi SW of North Appleton bridge
NORTH APPLETON LIMESTONE BELT
PIFSTER PROPERTY
NORTH APPLETON, MAINE
Plane Table Survey By
H.W. Allen & F.X. Groselle
MAINE GEOLOGICAL SURVEY, MAINE DEVELOPMENT COMMISSION
J.M. TREFETHEN, STATE GEOLOGIST
JULY, 1953

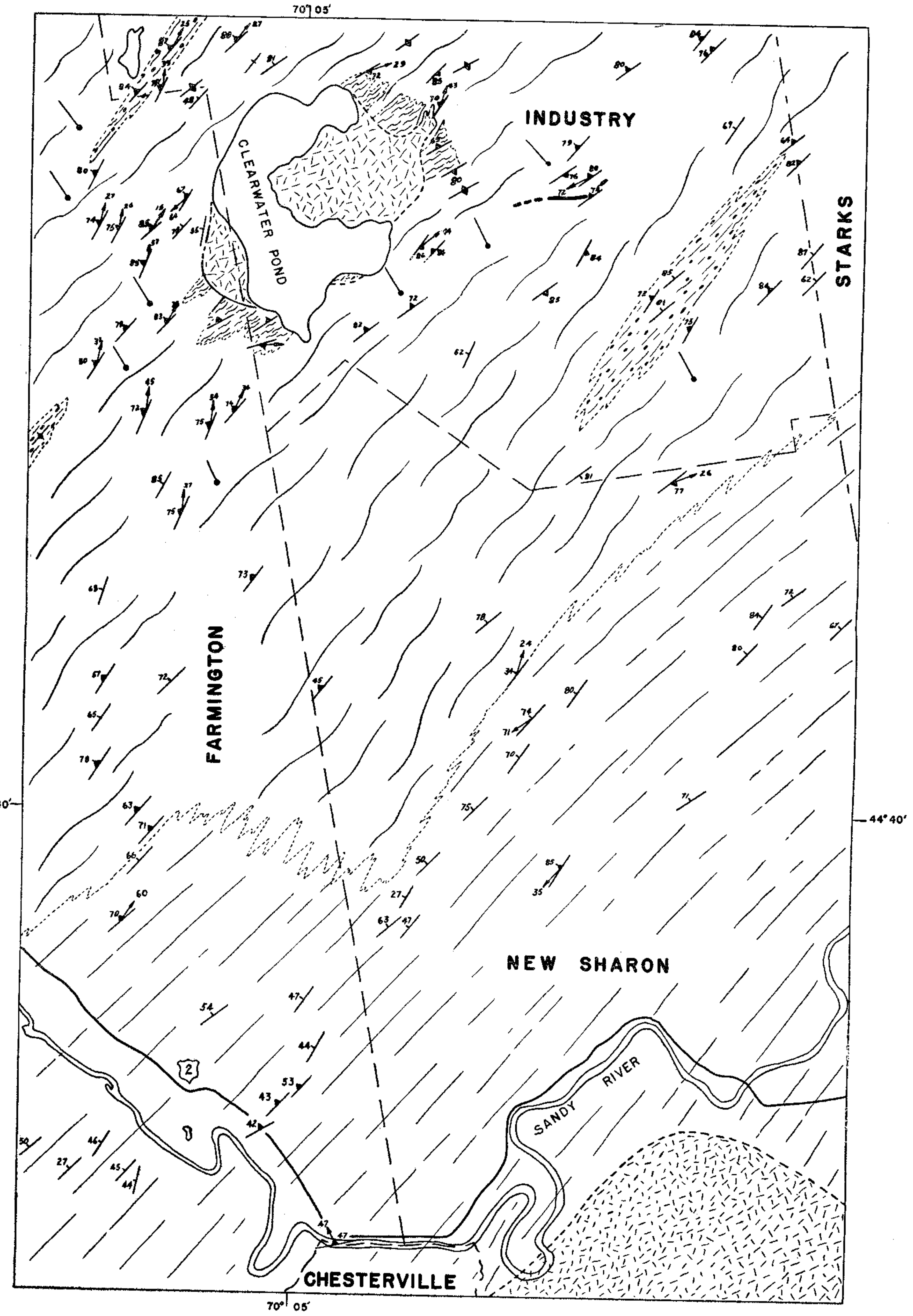


Map Showing N. Appleton and Lincolnville Limestone Belts


GEOLOGIC MAP
TO ACCOMPANY
FOREST CITY AREA
AIRBORNE MAGNETOMETER SURVEY
MAINE GEOLOGICAL SURVEY
J. M. TREFETHEN, STATE GEOLOGIST
LEGEND
METASEDIMENTS
Interbedded impure quartzite and phyllite
Red and grey-green slate
Limestone conglomerate
Black slate and quartzite with some grit
IGNEOUS ROCKS
Porphyritic white granite
Pink granite
Geologic contact approximately located
Dip and strike of bedding (vertical, inclined)
Dip and strike of foliation (vertical, inclined)
Flight strip boundary
Geology by W. T. Forsyth
1953
21°
68°00'
67°45'
67°30'
67°25'
46°00'
45°45'
45°30'
45°15'
CANADA
MAINE
LINNEUS
T A R2
RT. 2 ALT.
FORKSTOWN
CARY
AMITY
U.S. 1
HAYNESVILLE
ORIENT
BANCROFT
WESTON
AROOSTOOK CO.
WASHINGTON CO.
T8 R4
DANFORTH
RT. 169
BROOKTON
FOREST
VANCEBORO
T6 R3
LAMBERT LAKE
RT. 16
KOSSUTH
TOPSFIELD
CODYVILLE
WASHINGTON CO.
PENOBSCOT CO.
CARROLL
DYER
TALMADGE
WAITE
FOWLER
T5 R1
T6 R1
INDIAN
GRAND LAKE STREAM
T6 ND
T5 ND



67° 30'
45° 00'
GEOLOGY CONCEALED; POSSIBLY GRANITE
N
GEOLOGIC MAP
TO ACCOMPANY
MEDDYBEMPS AREA
AIRBORNE MAGNETOMETER SURVEY
MAINE GEOLOGICAL SURVEY
J.M. TREFETHEN, STATE GEOLOGIST
LEGEND
METASEDIMENTS
Light grey slate
Impure quartzite, locally with phyllitic layers
Sillimanite gneiss and impure quartzite
IGNEOUS ROCKS
Diorite and allied basic rocks
Granite-diorite breccia
Biotite granite, white feldspar
Biotite granite, pink feldspar
Molybdenite granite
Quartz porphyry, pink feldspar
Quartz porphyry, white feldspar
Magnetite bearing leucogranite
Inferred geologic contact
Inferred gradational contact
Shear zone
Dip and strike of bedding (vertical, inclined)
Dip and strike of foliation (inclined)
Geology by W.T. Forsyth 1953-1954



GEOLOGIC MAP OF THE NORTHEAST QUADRANT OF THE FARMINGTON QUADRANGLE

FRANKLIN AND SOMERSET COS., MAINE

GEOLOGY BY GARY M. BOONE

1 1/2 0 1 2 MILES

POST MIDDLE DEVONIAN

GRANODIORITE AND ALASKITE

GRANODIORITE PORPHYRY

PRE MIDDLE DEVONIAN

SOUTHERN GROUP

QUARTZ-BIOTITE SCHIST AND GNEISS, LIME SILICATE SCHIST AND GNEISS, STAUROLITE-ALMANDINE SCHIST

NORTHERN GROUP

QUARTZ-BIOTITE SCHIST, QUARTZITE, AND SLATE; MINOR GRAYWACKE

GRAYWACKE; MINOR QUARTZ-BIOTITE SCHIST, QUARTZITE, AND SLATE

ANDALUSITE-ALMANDINE SCHIST

27 STRIKE AND DIP OF BEDDING

67 60 STRIKE AND DIP OF FOLIATION, BEARING AND PLUNGE OF LINEATION

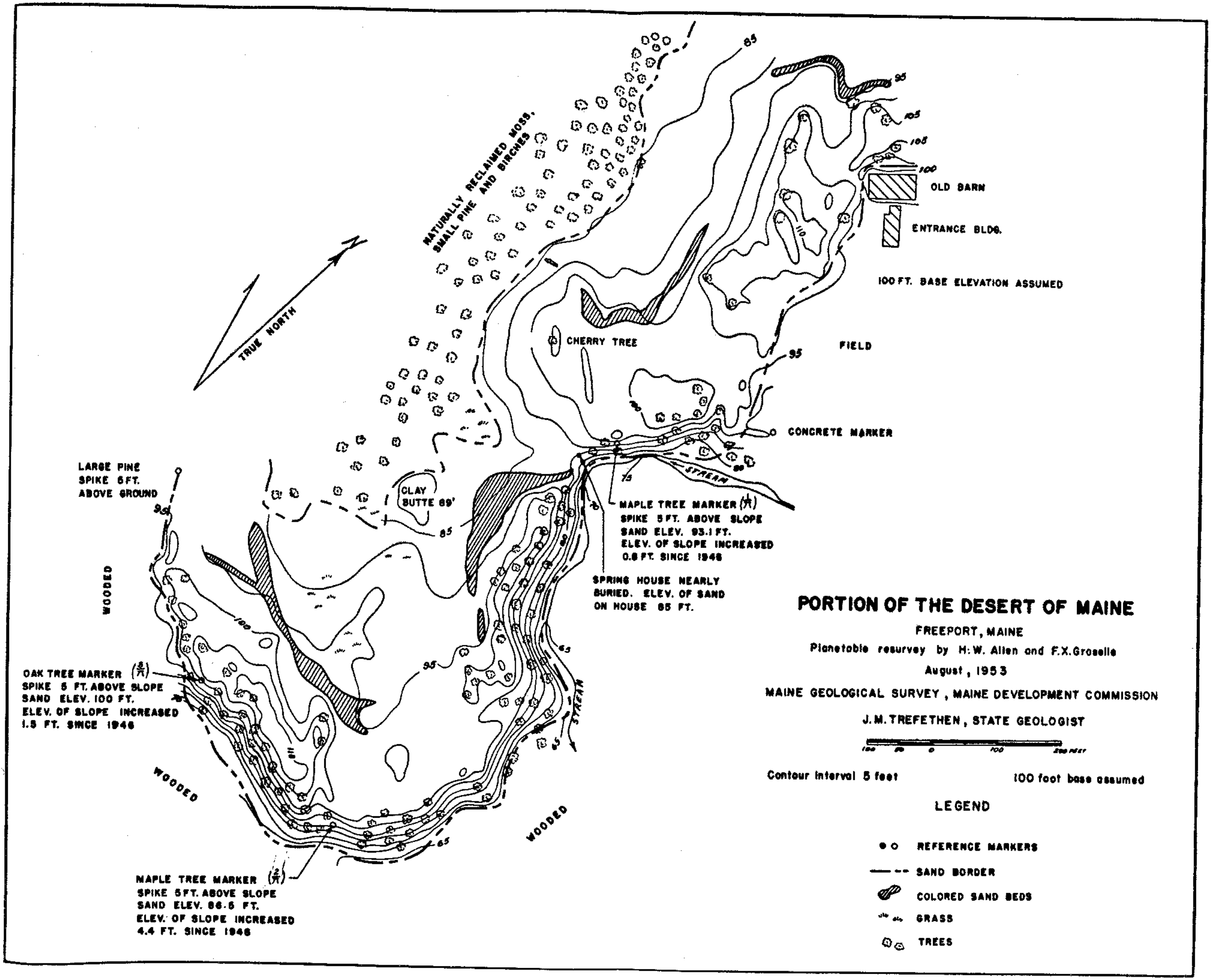
STRIKE AND DIP OF FOLIATION WHERE PARALLEL TO BEDDING

GLACIAL STRIAE

CONTACT, EXPOSED OR CLOSELY LOCATED

CONTACT, CONCEALED

CONTACT, GRADATIONAL


PORTION OF THE DESERT OF MAINE
FREEPORT, MAINE
Planetable resurvey by H. W. Allen and F. X. Groselle
August, 1953
MAINE GEOLOGICAL SURVEY, MAINE DEVELOPMENT COMMISSION
J. M. TREFETHEN, STATE GEOLOGIST
Contour interval 5 feet
100 foot base assumed
LEGEND
REFERENCE MARKERS
SAND BORDER
COLORED SAND BEDS
GRASS
TREES
TRUE NORTH
NATURALLY RECLAIMED MOSS, SMALL PINE AND BIRCHES
OLD BARN
ENTRANCE BLDG.
100 FT. BASE ELEVATION ASSUMED
FIELD
CHERRY TREE
CONCRETE MARKER
STREAM
MAPLE TREE MARKER (1/T)
SPIKE 5 FT. ABOVE SLOPE
SAND ELEV. 93.1 FT.
ELEV. OF SLOPE INCREASED
0.8 FT. SINCE 1946
SPRING HOUSE NEARLY
BURIED. ELEV. OF SAND
ON HOUSE 85 FT.
LARGE PINE
SPIKE 5 FT.
ABOVE GROUND
CLAY
BUTTE 69'
WOODED
OAK TREE MARKER (3/T)
SPIKE 5 FT. ABOVE SLOPE
SAND ELEV. 100 FT.
ELEV. OF SLOPE INCREASED
1.5 FT. SINCE 1946
MAPLE TREE MARKER (2/T)
SPIKE 5 FT. ABOVE SLOPE
SAND ELEV. 86.5 FT.
ELEV. OF SLOPE INCREASED
4.4 FT. SINCE 1946
WOODED
WOODED
STREAM
85
95
105
105
100
110
95
100
75
80
85
95
100
95
65
65
65
100

MAINE GEOLOGICAL SURVEY

REPORTS

"First Annual Report on the Geology of the State of Maine" by Lucius H. Merrill and Edward H. Perkins, 1930.*
"State Geologist's Report on the Geology of Maine 1930-32" by Joseph C. Twinem and Edward H. Perkins.*
"Preliminary Geological Map of Maine" by Arthur Keith and Edward H. Perkins, 1933.*
"Report of the State Geologist, 1941-42" by Joseph M. Trefethen.*
"Report of the State Geologist, 1943-44" by Joseph M. Trefethen.*
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"Domestic Fuel Possibilities of Maine Peat" by Joseph M. Trefethen and Robert B. Bradford.
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"Economic Geology of Some Pegmatites in Topsham, Maine" by Vincent E. Shainin.
"Pegmatites and Associated Rocks in the Newry Hill Area, Oxford County, Maine" by V. E. Shainin and Louis Delwig.
"Genetic Study of Some Pyrrhotite Deposits of Maine and New Brunswick" by Robert S. Houston.

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"Aeromagnetic Survey and Geologic Reconnaissance of the Forest City Area, Washington and Aroostook Counties, Maine" by William T. Forsyth.
"Aeromagnetic Survey and Geologic Reconnaissance of the Meddybemps Area, Washington County, Maine" by William T. Forsyth.
"Aeromagnetic Survey of the Dead River Area, Oxford, Franklin and Somerset Counties, Maine" by the United States Geological Survey in cooperation with the State of Maine.
"Aeromagnetic Profiles in the Rochester-Berwick Area, New Hampshire and Maine" by the United States Geological Survey.

MAPS

"Aeromagnetic Survey and Geologic Reconnaissance of Part of Piscataquis County, Maine" by E. P. Kaiser and J. R. Balsey, U.S.G.S. Geophysical Investigations Map GP 116, 1954. In cooperation with the State of Maine.

OTHER

"Bibliography of Maine Geology, 1931-1954" by William T. Forsyth.

Copies obtainable on request to the Department of Development of Industry and Commerce, Augusta, Maine.

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* Out of stock